THE WEATHER AND CIRCULATION OF OCTOBER 1956[1]

Including a Discussion of the Relationship of Mean 700-mb. Height Anomalies to Sea Level Flow

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1. WEEKLY CIRCULATION STATES RELATED TO DROUGHT RELIEF

As October began, critical drought conditions prevailed over most of Texas, the Central Plains, and southeastern Rocky Mountain States. Moisture deficiencies, particularly during the growing season, had mounted to record proportions in some areas; e. g., western Texas was already in its sixth year of drought [11]. Unirrigated crops had been a failure, pastureland of little use, and there was insufficient moisture for germination of seed for winter small grains.

First week.—Salient details of the first week in October are pictured in figure 1. Over North America the gross features of a ridge in the West and a trough in the East continued, as in September, to be the overriding characteristics [3]. Warmth predominated over the United States with ridge conditions along the eastern Rockies (fig. 1a) and heights well above normal aloft. The eastern North American trough was stronger than normal and off the coast in the north, although it lay inland over the Appalachians in the south. At sea level (fig. 1b), a maritime high pressure ridge extended from the Far Northwest to the Central Plains. With the exception of extreme eastern Texas and central California, no precipitation of note occurred west of the Mississippi-Ohio Valleys (fig. 1d). Widespread rains in the East were due to cyclonic activity in the Appalachian trough. The rather unseasonal California precipitation was associated with entry of a cold front into the closed California Low shown in figure 1a. No appreciable drought relief was experienced in central United States.

Second week.—Significant changes in circulation became manifest toward mid-month. During the last five days of this period (fig. 2a and b) mean ridge conditions at 700 mb. moved rapidly northeastward toward the central Appalachians. The closed Low off the California coast (fig. 1a) was gradually transformed into a vigorous polar trough. The entire west coast was now subjected to the effects of westerly perturbations which gradually extended their area of influence to lower United States latitudes.

In the fast westerly band across the North Pacific (cf. 700-mb. and sea level patterns in fig. 2) disturbances travelled rapidly eastward. Although major centers passed into central Canada (Chart X), trailing fronts and secondary centers brought cold air and precipitation into the Northwest. Toward the end of this period, an upper-level cyclonic circulation worked eastward at lower latitudes to the midcontinent and in concert with the frontal advance of cold air, effected a meridional release of precipitation which fell in a swath from southern Texas to the western Lakes (fig. 2d).

While these welcome rains fell in the Midwest, the East was enjoying one of its famous spells of fine autumn weather. This resulted from eastward motion of the upper-level ridge (noted above) in conjunction with a cold Canadian High at sea level. The High swept down out of Canada on the 9th (Chart IX) and passed eastward into New England. The upper-level ridge came eastward during this period and intensification at both levels took place from the southwestern Appalachians into New England. Dynamic anticyclogenesis was apparently involved in the maximum sea level pressure (daily) of 1040 mb. noted in New England on the 12th. Although the high center passed off eastward, ridge conditions were maintained over much of the East and in the almost stagnant circulation the cumulatory effects of industrial pollution of the air were noted in a number of eastern cities. In general, however, crisp cool nights and hazy autumn days were the order, except in those more southerly areas where onshore easterly flow to the south of the ridge line brought cloudiness and precipitation (note Florida, fig. 2d). Simultaneously the mid-United States was warmed by return flow to the rear of the High, but the East remained below normal due to the initial low temperatures of the Canadian air.

Third week.—Further extension of weak westerly influence into central and southeastern United States was noted during the third week. (See fig. 3a for latter part of week.) Most noteworthy event was the slow movement across the southern United States of an upper-level cyclonic circulation which spread precipitation from New Mexico eastward. Central and southern Texas received 1 to 2 inches generally, and temporary local drought relief was accomplished (fig. 3d). Heavy amounts of rainfall were

[1] See Charts I–XVII following p. 377 for analyzed climatological data for the month.

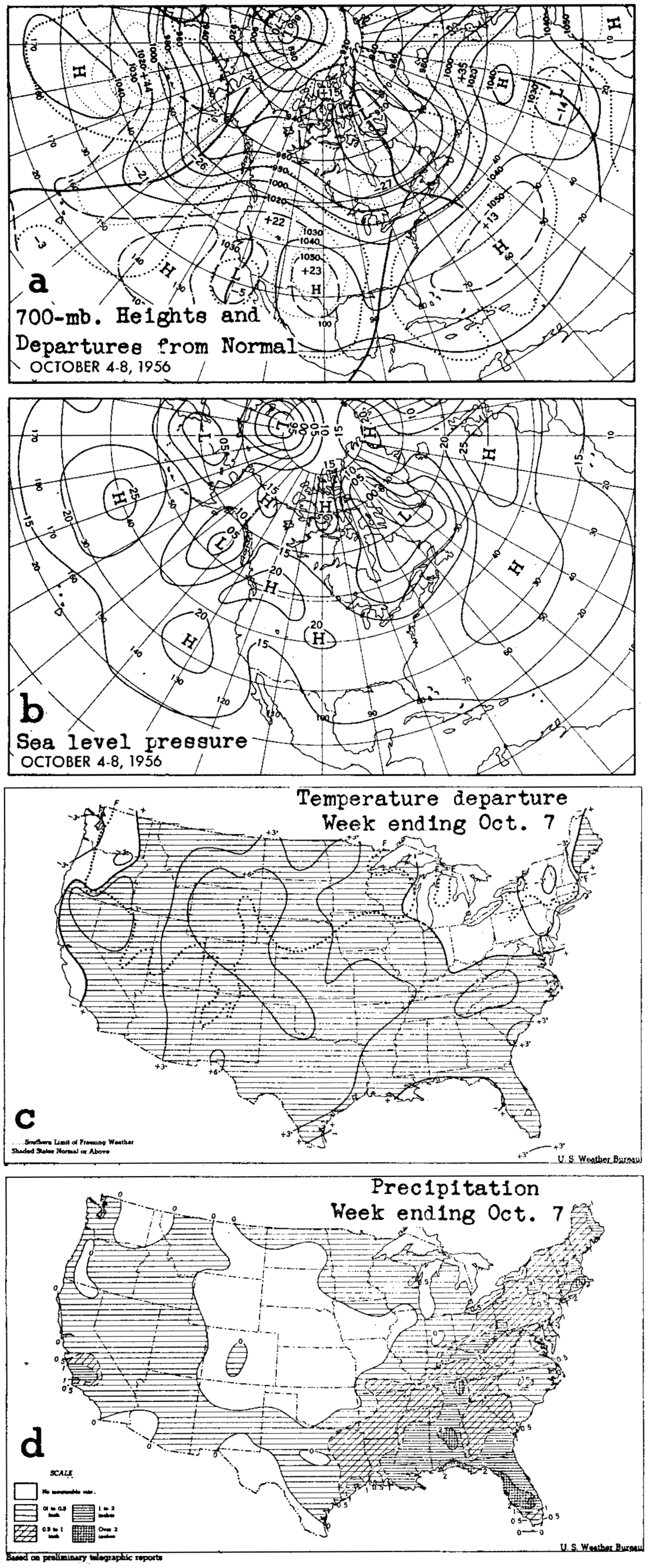

FIGURE 1.—(a) and (b) 5-day mean 700-mb. and sea level charts showing continuation of September pattern of mean ridge west of Continental Divide with mean trough along or off the east coast. (c) and (d) show continuation of September's temperature and precipitation regime with no drought relief in central United States.

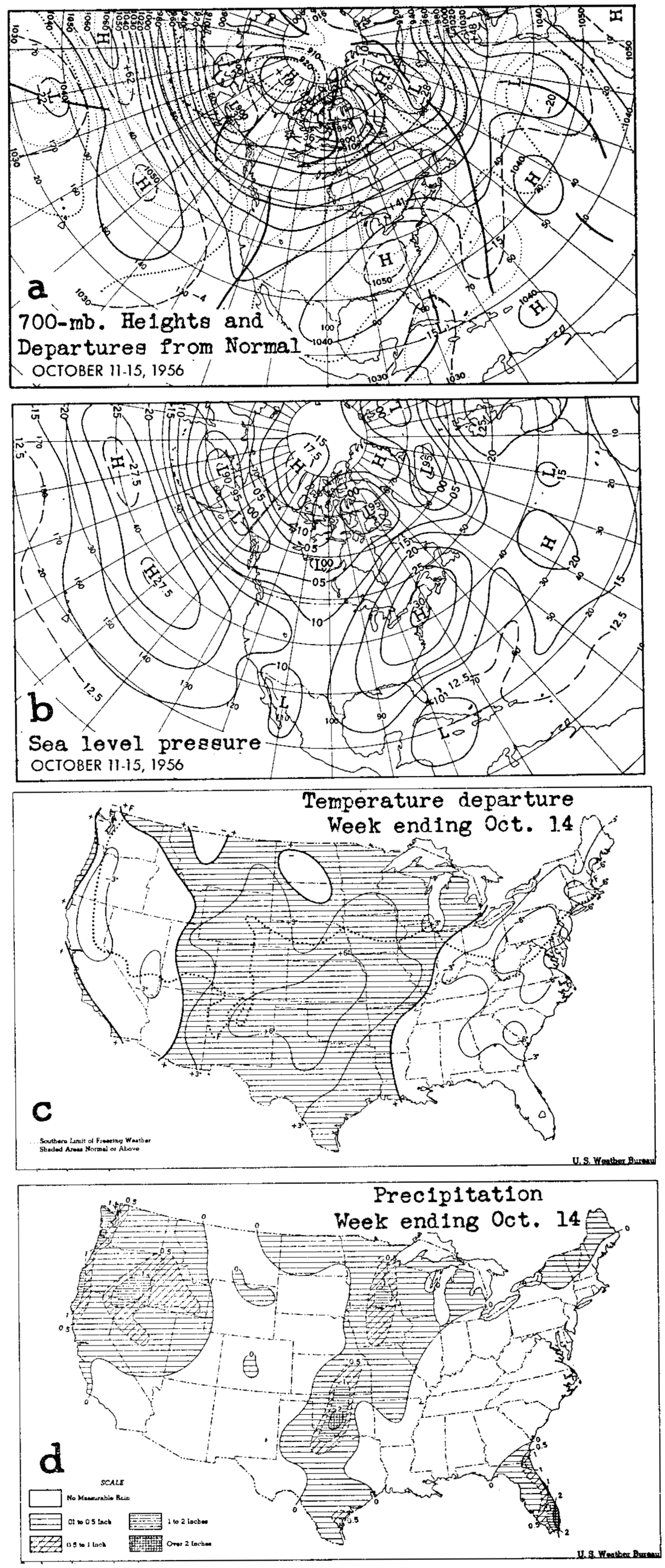

FIGURE 2.—Major changes in circulation pattern took place toward middle of month. Development of west coast trough and rapid motion of mean ridge into Northeast (a) and building of dynamic anticyclone in New England (b) brought changes in temperature regime, (c) and first Midwest drought relief (d).

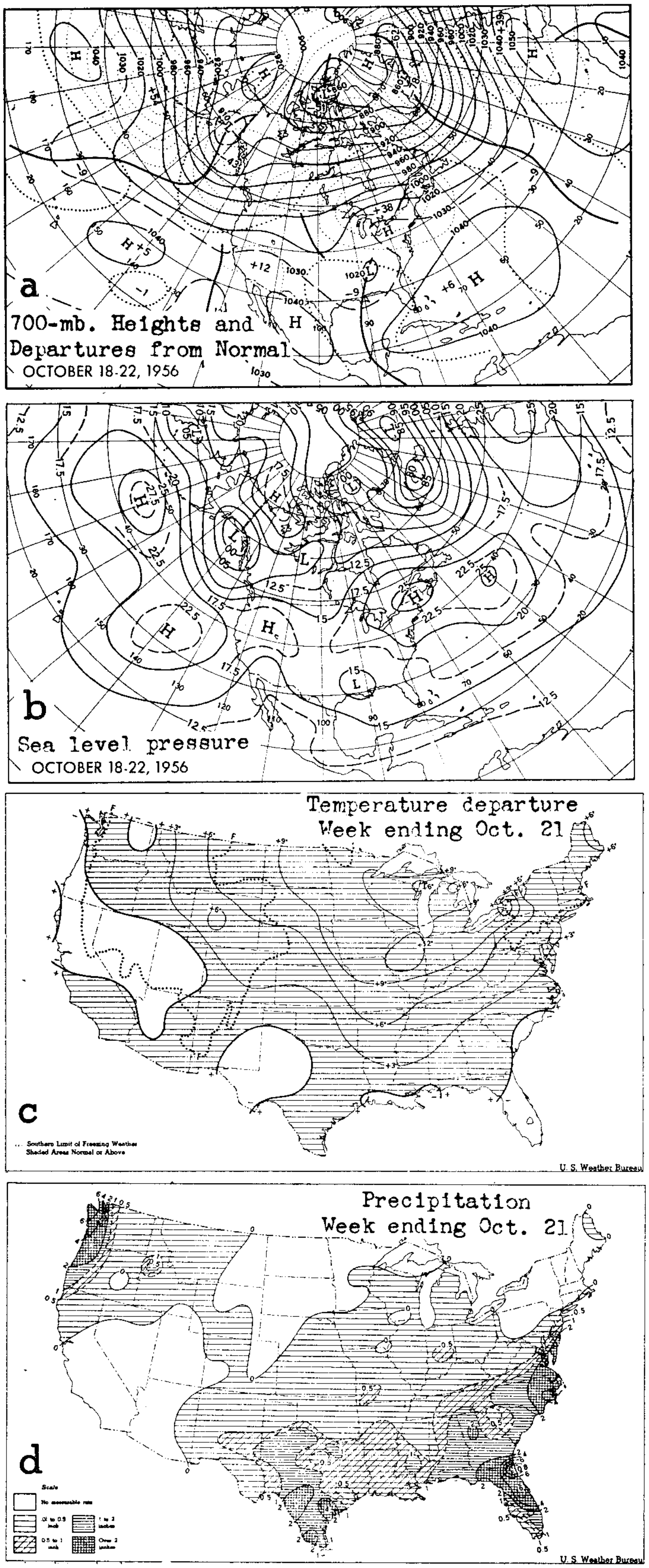

Figure 3.—Gradual penetration of influence of the westerlies into central and south-central United States during third week is indicated in (a) and (b). Warming in west (c) accompanied southerly anomalous flow (a). Precipitation in Texas seems most closely related to passage of upper-level cyclones. Note east coast precipitation due to semitropical Low.

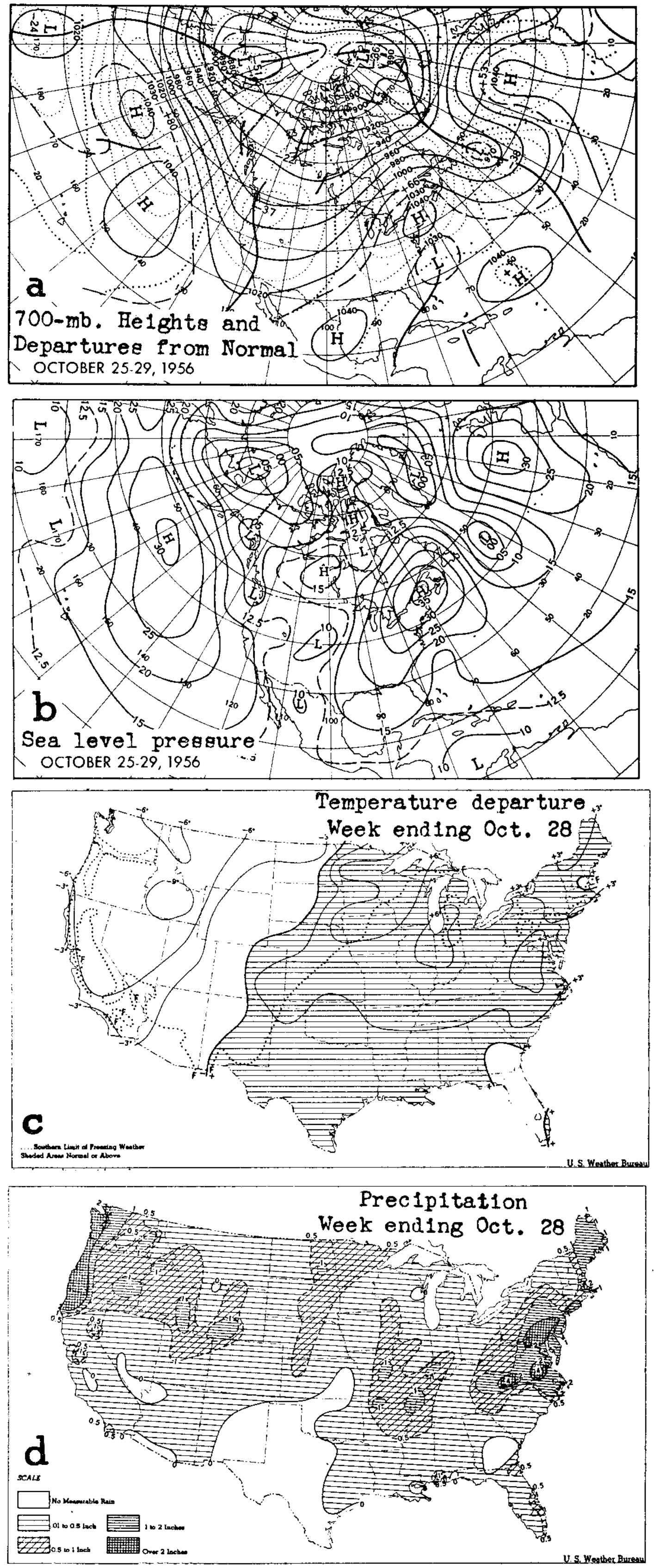

Figure 4.—(a) and (b) show an intensification of the new pattern which first emerged in figure 2. Fresh cold air from the north Pacific was swept through the trough to the Divide (c) as precipitation spread eastward. Note rain-shadow over much of drought area (d), with precipitation in Mississippi Valley in region removed from foehn components (a).

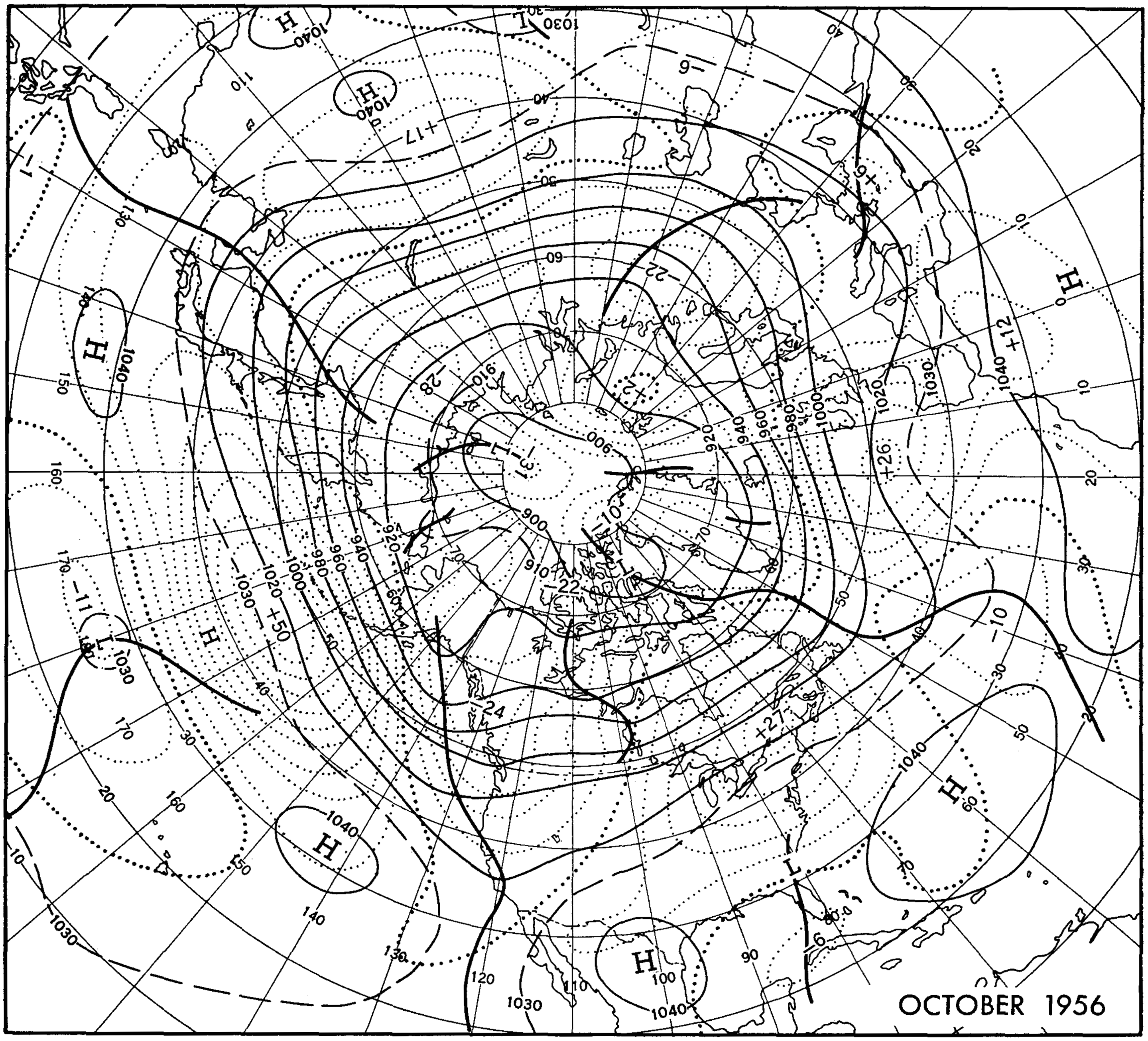

FIGURE 5.—Mean 700-mb. height contours and departures from normal (both in tens of feet) for October 2–31, 1956. Abnormal Pacific ridge led to strong development of west coast trough and complete suppression of east coast trough activity except in Florida.

also noted in the far Northwest, with strong onshore flow or trailing fronts providing daily rains.

Anticyclonic circulation maintained itself over New England (fig. 3b) as two new migratory Highs entered this area during the week (Chart IX). This continued the regional circulation pattern established the preceding week, which was reintensified during the last week (fig. 4a, b). Early in the third week a "semitropical" Low formed near Cuba in the easterlies well south of the High over New England. The Low moved up along the Florida coast and turned abruptly eastward only after reaching Chesapeake Bay on the 18th (Chart X). This turn was achieved during a momentary relaxation of the New England blocking as a fresh cold surge moved in. The storm left two or more inches of precipitation along most of the coast from Florida to southern New Jersey. St. Cloud, Fla., reported 17.30 in.

Temperatures were generally warm during this third week. An influx of marine air accompanying the storm noted above and rapid passage of Highs off the coast restored above normal conditions to most of the East (fig. 3c). In the West, the major trough was off the coast, and Pacific air from a more southerly and warmer source moderated previously cool conditions.

Fourth week.—During this period a return to, and intensification of, the general circulation type of the second week was noted. The west coast trough and New England High became stronger than before (fig. 4a and b). This was part of a general increase in amplitude of the mid-latitude wave system (fig. 4a) and a marked decline in zonal westerlies from what had been a typical October high index.

Below normal temperatures again dominated the West (fig. 4c), as the eastern Pacific trough came eastward and great quantities of cold North Pacific air were swept inland. Precipitation (fig. 4d) extended from the Mexican to the Canadian border in the West, with greatest amounts in the Northwest, where heights were below normal and cyclonic activity most marked. Again precipitation spread eastward as westerly perturbations were propagated downstream. A prelude to winter could be seen in the storm of the 23d to 24th which left up to 2 feet of snow in the northern Cascades; 19 inches at Alta, Utah; lesser amounts over Colorado and Wyoming; and 6 inches over the Black Hills of South Dakota.[2] As the cold air advanced eastward, precipitation also fell over the Northern and Eastern Plains, but foehn action extended the rain shadow of the Rockies over most of Texas.

The eastern half of the country was warm since the two daily Highs affecting the area were mainly of modified Pacific air (Chart IX). Precipitation in the East was associated with cyclonic developments in the east coast trough and orographic control of the strong onshore moist flow.

In the last few days of October (not shown here) another westerly disturbance worked eastward at lower latitudes from the west coast trough. Modest but significant amounts of precipitation fell over much of the drought area.

Thus October brought temporary relief to many critical drought areas. The further restoration of soil moisture and adequate water tables remained to the future.

2. MEAN CIRCULATION OF THE MONTH

From the preceding rather thorough sampling of the month one should be able to estimate the monthly mean state without great difficulty. Figure 5 shows the mean 700-mb. circulation pattern and accompanying height departures from normal. The westerlies were stronger and farther north than normal with essentially four mid-latitude troughs—not counting a weak lee-trough east of the Canadian Divide. In the Pacific, an anomalously long wavelength existed; the troughs were on either shore, separated by an elongated ridge. Across the northern periphery of the ridge lay a strong, fast westerly belt, while in the ridge itself heights were 500 ft. above normal. This is the greatest positive (hemispheric) anomaly of record for October.

In retrospect one can see that the first week of October (fig. 1a) was essentially a continuation of the regime which prevailed during September [3]; i. e., an east coast trough and a ridge west of the Divide. Only in the second week of October, as the west coast trough deepened and anticyclogenesis prevailed over the East (fig. 2), did the new regime become manifest. During the last two weeks secondary variations of the new pattern prevailed. Consequently, there was a considerable change in circulation type over North America between September and October and, as we have seen, a significant change in certain aspects of the precipitation distribution. An exception to the general change, however, should be noted in the low-latitude trough over Florida which represented little variation in circulation or weather for this area. For the country as a whole, temperature changes were greater than average; i. e., 58 percent of the stations changed temperature by more than one class [3] compared to 35 percent normally anticipating so great a change from September to October.

Another interesting facet of October's weather has been pointed out by Ballenzweig. In recent research on hurricanes [1], he has established that patterns similar to figure 5 are generally favorable to hurricane development and subsequent incidence in the Florida area. How then does one account for only one "semitropical" Low this October? His precursory survey of sea surface temperatures as plotted on current weather maps was expanded and is presented in figure 6. Although complete data are not yet available, those so far examined show surface water temperatures this October were below normal [10] and almost all boxes were below 81°–83° F., which Palmén has noted as approximately the lowest water temperature over which hurricanes are likely to form [12]. Just how

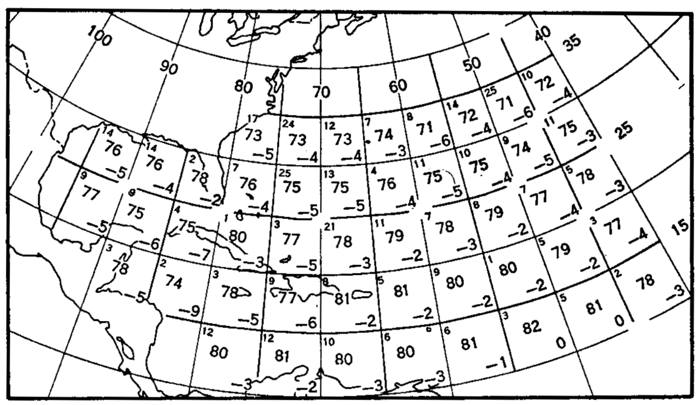

Figure 6.—Preliminary survey of sea surface water temperatures (°F.) for October from plotted synoptic data on eleven selected days. Key: in upper left corner of square, number of observations; center, mean sea surface temperature; lower right, departure from normal. Data far from complete but strongly suggest prevalence of cooler than normal conditions.

[2] See adjacent article by Vore and McCarter discussing forecasting problems associated with this type of development.

[3] Monthly temperature classes are defined with reference to the monthly variability and normal temperature for each station. Limiting departures are determined from past records so that classes below, near, and above normal each occur ¼ of the time, while much below and much above occur ⅛ of the time.

successfully these anomalies can be related to the atmospheric circulations of preceding months is beyond the scope of this note. However, both August and September were conspicuous for strong westerly trough activity in western and eastern sectors of the Atlantic. In fact, the discussion of September [3] mentioned the unconfirmed report of an ice floe sighted near the Azores in uncommon southerly latitudes. Since water temperature anomalies are usually assumed to change but slowly, there is here a definite suggestion (cf. Riehl [14]) that such anomalies have prognostic implications. For a month with similar regional circulation characteristics, but with hurricane activity, the reader is referred to October 1947 [4]. It should also be mentioned that the Low near Cuba (Chart X) on the 30th and 31st became a full-fledged hurricane on November 4.

3. MEAN HEIGHT DEPARTURES FROM NORMAL AND WEATHER ANOMALIES

In the course of this series of articles considerable attention has been paid to the relation between surface weather and mean 700-mb. height anomalies. The usual procedure is to interpret the height anomaly gradients by means of the geostrophic relationship and to speak of "anomalous components" of flow. This departure from normal (DN) flow may be considered as that flow which, when added to the appropriate normal flow, would yield the observed flow pattern. Relating mean states of temperature and precipitation to the observed mean 700-mb. flow pattern is rendered much easier through explanations couched in terms of the DN flow, as if the flow has direct physical existence. The general success of this approach has won it a certain degree of acceptance, but no explicit justification of its employment has been attempted. It is therefore proposed that some further rationalization be offered here.

One of the most convincing demonstrations of the utility of thinking in terms of DN flow was offered in Martin's temperature studies [8] and, to a lesser extent, in those of Hawkins relating to precipitation [8]. The common employment of DN flow in the work of the Extended Forecast Section [9] stems from about this time (1949) and the concept was employed from the very first in these monthly articles on weather and circulation [6]. It is the author's opinion that this has proven to be a justifiable procedure and that the success noted was because there are component flows on the observed sea level patterns which correspond, on the whole, quite closely to the concomitant 700-mb. height departure from normal (DN) patterns. This might be extended to the effect that, strong gradients of 700-mb. DN flow usually resemble the total observed flow at sea level. Where the DN flows are weak, and over continental areas in general, this correspondence becomes less well marked. In view of the fact that we are concerned with mean maps, and that cold Lows and warm Highs are the more stable and longer-lived elements

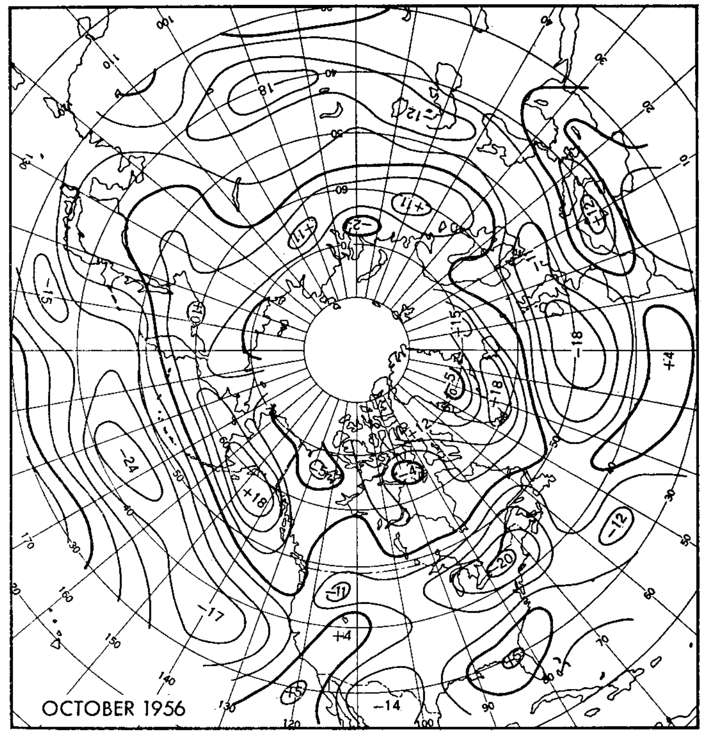

FIGURE 7.—Vertical component of mean relative geostrophic vorticity at 700 mb. for October 2–31, 1956. Centers are labeled in units of 10^{-6} per second, negative-anticyclonic, positive-cyclonic. Compare overall field with height departures from normal (fig. 5), and sea level mean pressure (fig. 8).

contributing to these means, the total resemblance essentially reaffirms the hydrostatic equation if one admits the persistent recurrence of given circulation states. On the other hand, shallow Highs and Lows are subject to steering by the upper-level currents. These upper currents are then generally indicative of the deployment of this class of sea level systems.

In this latter connection previous work related the tracks of daily sea level cyclones and anticyclones to the relative vorticity field at 700 mb. [5, 13]. The relation between height anomalies and relative vorticity is quite straightforward, since the anomaly centers are, in effect, the perturbations superposed upon a normal field of almost straight westerly flow. If one compares the departures from normal in height (fig. 5) with the 700-mb. field of relative vorticity (fig. 7) the general similarity is quite evident. Correspondence of significant centers was excellent. For example, major positive anomaly centers in the Pacific, St. Lawrence Valley, eastern Atlantic, and southern Siberia found direct reflection in the anticyclonic (negative) vorticity centers; in like manner, the stronger negative height centers in the Gulf of Alaska, off southeastern Greenland, over European Russia, and in northeastern Siberia had cyclonic relative vorticity centers associated with them. The correlation coefficient between 700-mb. height departure from normal pattern (fig. 5) and the 700-mb. field of relative vorticity (fig. 7) was computed

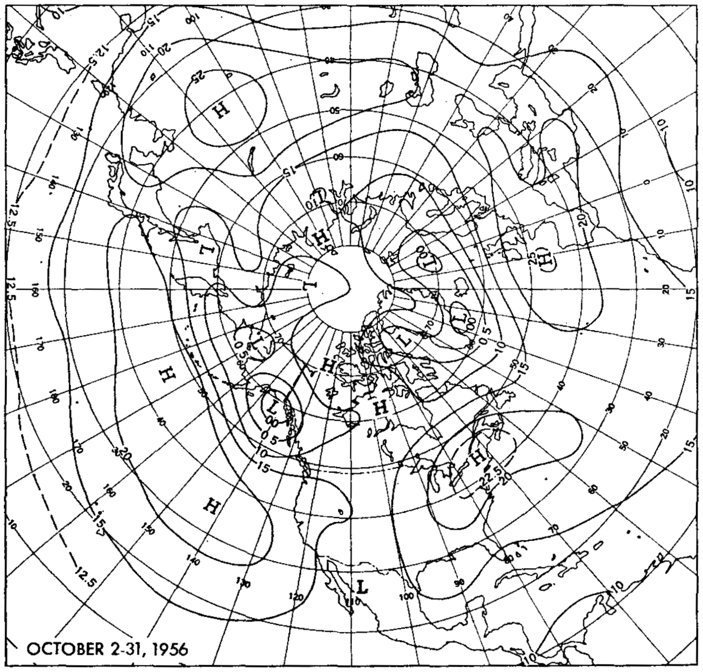

FIGURE 8.—Thirty-day mean sea level pressure, October 2–31, 1956. Strong High over New England resulted in onshore moist currents over most of east coast and warm return flow in central United States. Strong Gulf of Alaska Low was accompanied by weak Basin ridge and anomalous cyclonic activity along west coast of North America.

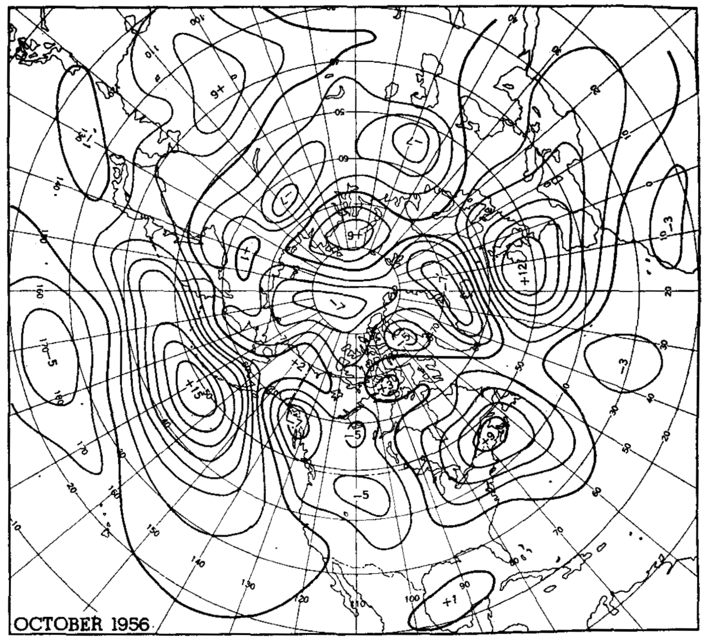

FIGURE 9.—Mean sea level pressure departure from normal for October 2–31, 1956. Note similarity in field of departures to height departure field (fig. 5), also correspondence of strong gradients with sea level gradients (fig. 8).

at 72 points distributed evenly around the hemisphere between 30° and 60° N., inclusive, and was found to be −0.70.

Actually, the relative vorticity field at 700 mb. can also be directly related to the field of total sea level pressure. This connection may be found in earlier articles (e. g., Klein [5]) but a forthright statement of the relation has been lacking. Presumably through the agency of the hydrostatic equation, well-marked centers of vorticity (fig. 7) can usually be related to similar centers at sea level (fig. 8). The correlation between the patterns of figures 7 and 8 on the 72-point grid was found to be −0.74. This was larger in magnitude than the correlation between 700-mb. height departures from normal and the mean sea level pressure pattern, which was 0.63 for an 81-point grid (including data at 75° N.). Thus the 700-mb. height departures from normal are closely related to the field of relative vorticity (at 700 mb.) and, to a slightly lesser degree, to the sea level pressure field itself.

Of greater relevance to the general problem is the relation between the upper-level height departures from normal (fig. 5) and the sea level departures from normal (fig. 9). Inspection reveals that, although the maps were not identical, overall similarity was striking. The correlation coefficient between the two patterns, computed at 81 points distributed evenly around the hemisphere between 30° and 75° N., was 0.82. This demonstrates the desired relationship since the prime requisite is that the anomalous, or abnormal, sea level flow be closely related to the 700-mb. height DN flow. In essence this infers that the immediate causes of the mean temperature and (to a lesser extent) precipitation departures from the climatic average are abnormal components of flow in the lower troposphere.

The general mode of thinking outlined above is far from new but explict demonstrations have been seldom offered. Nonetheless, objections to the use of any departure from normal map as depicting a real physical entity are commonly met. More recently the mathematical expression of any flow field in terms of normal and abnormal components and the utility of such representation has become more generally appreciated [2]. In practice, one finds few, if any, cases in which mean DN flows of significant intensity do not have actual physical currents of like nature on some of the daily synoptic charts which contribute to the series. Comparisons can also be made between 5-day mean height departures at 700 mb. and the concurrent sea level patterns in figures 1 through 4. Where DN gradients were strong, sea level gradients were quite similar. In a number of instances surprising correspondence of detail can be noted.

In application then, one would associate the below normal temperatures in the West (Chart I-B) with the abnormally strong fetch of cold air from the northeastern Pacific into the western United States, indicated by the departure from normal flows at 700 mb. (fig. 5) and at sea level (fig. 9). The same deductions are possible from the total observed sea level pattern (fig. 8) although only comparison with the normal (i. e., fig. 9) or an analog will reveal the inherent abnormality in figure 8. In like fashion, the prevailing warmth over the central United States occurred where DN flows were southerly or weak and slightly anticyclonic. The east coast was warm in central sections where onshore, warm, moist flow was strong, but below normal in temperature over Florida, where cyclonic circulation and cloudiness were dominant, and below normal in southern New England, where radiation effects were at a maximum at the center of the sea level High (fig. 8).

Precipitation amounts are (often less directly) associated with the circulation anomalies relative to the pertinent moisture source regions. For instance, precipitation in the West (Charts II and III) was due to the strong onshore flow, trailing frontal passages in the trough, and cyclonic developments which occurred immediately downstream from the trough. This could be inferred from either figures 5, 8, or 9, but appears more clearly delineated in the height anomalies of figure 5, or the pressure anomalies of figure 9. Similarly, most of the east coast precipitation could be associated with onshore easterly flow and perturbations associated with it. Heaviest amounts occurred in the central sector, where onshore flow was strongest, and over Florida where cyclonic circulation, at sea level and aloft, was most marked. Precipitation totals in the central portion of the country were comparatively small and, in proportion, less directly related. The precipitation was released by perturbations travelling downstream from the west coast trough, with moisture supplied from the Gulf of Mexico and advected northward around the ridge in the East.

The general utility of concentrating attention upon abnormal flow features to explain anomalies in weather has been pointed out in many and diverse writings. The application of this concept to mean flows is both logical and demonstrable. However, it must be expected that, when time means are used, best results will be obtained when dealing with meteorological elements which are continuous in nature and appropriate to time averaging; i. e., temperature, humidity, etc. A discontinuous element such as precipitation does not lend itself as readily to such treatment, although Stidd's work [15] seems to indicate that when longer and longer time means are employed, even these elements can be successfully treated. The trend of modern meteorology is definitely toward the prediction of circulation states, although exceptions may be noted. The value of using the departure from normal concept in interpreting these states in terms of weather is believed to be both sound and useful. Furthermore, it is possible that one of the more promising available attacks on the problem of long-range forecasting lies in the treatment of evolution of circulations primarily through consideration of the field of height anomaly [7].

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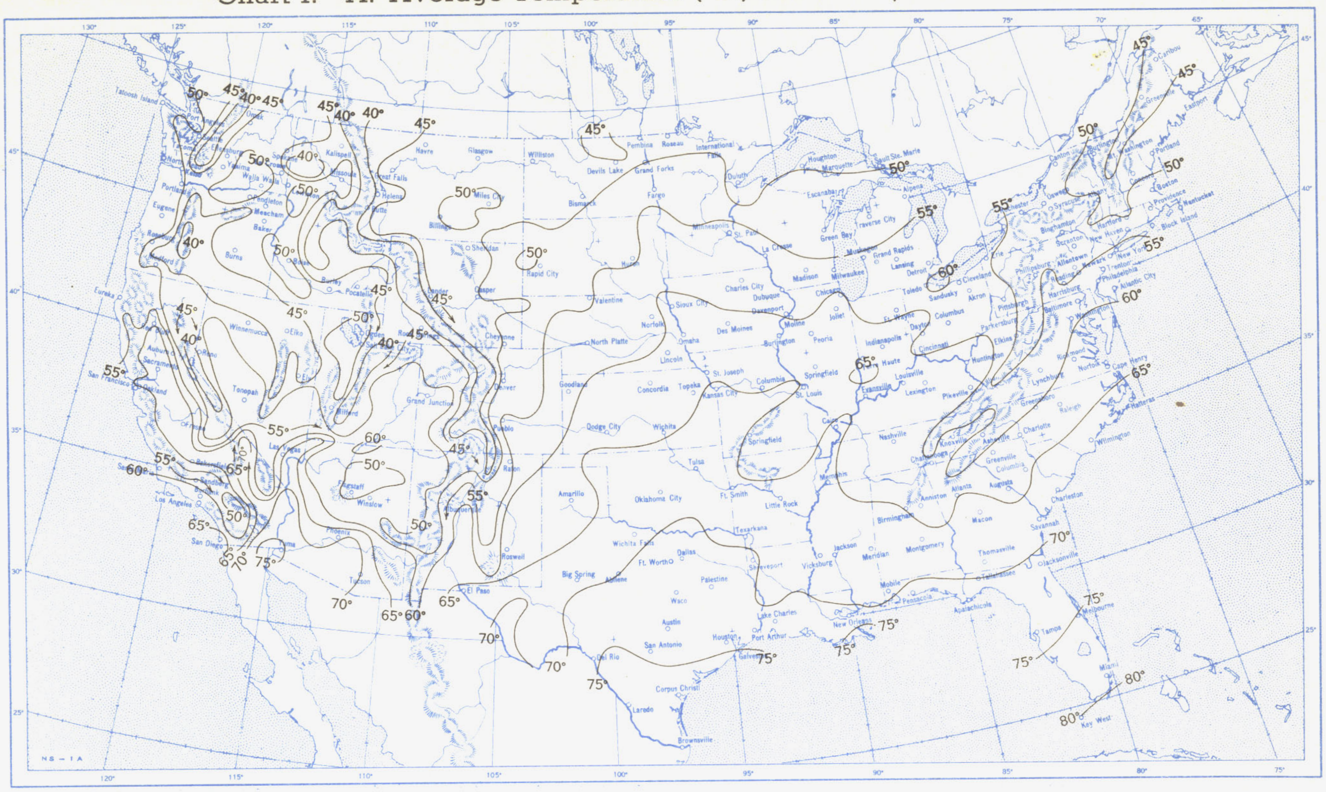
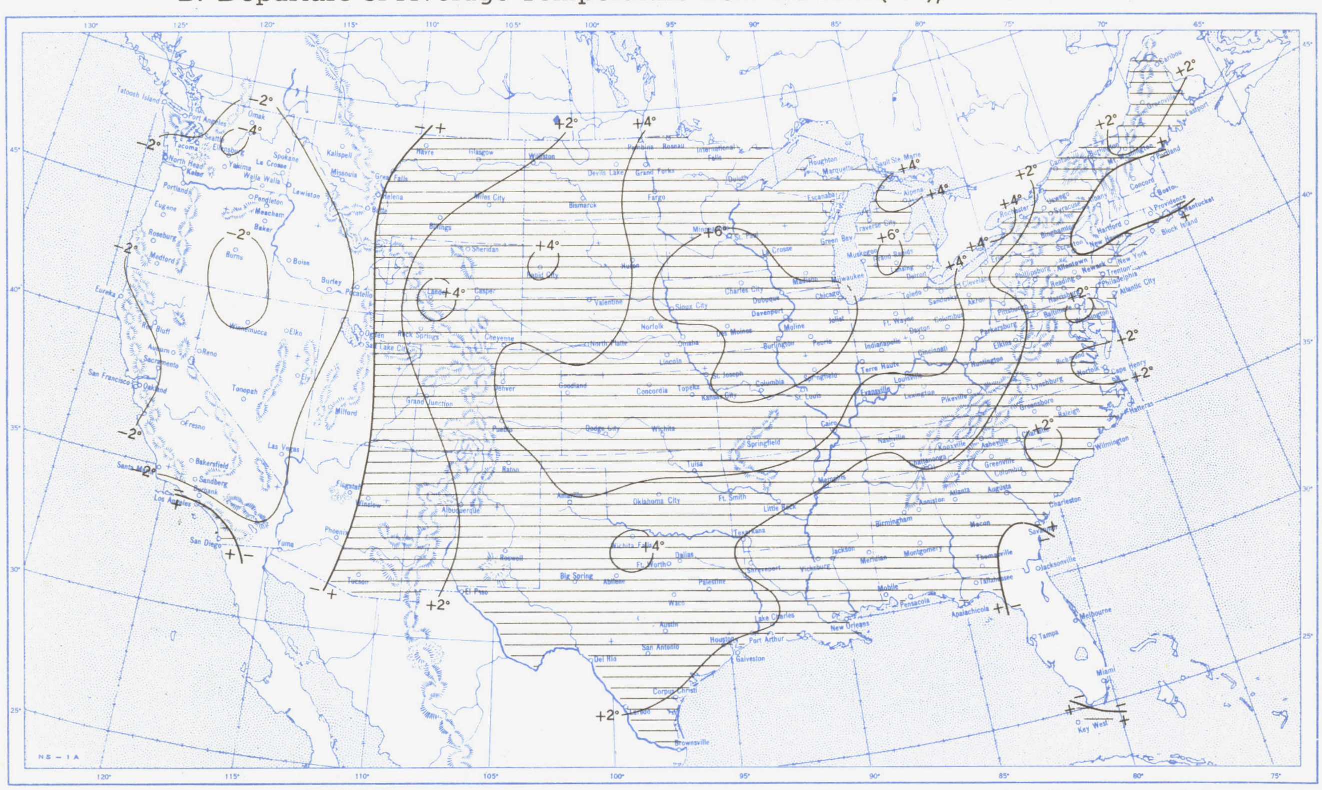
Chart I. A. Average Temperature (°F.) at Surface, October 1956.

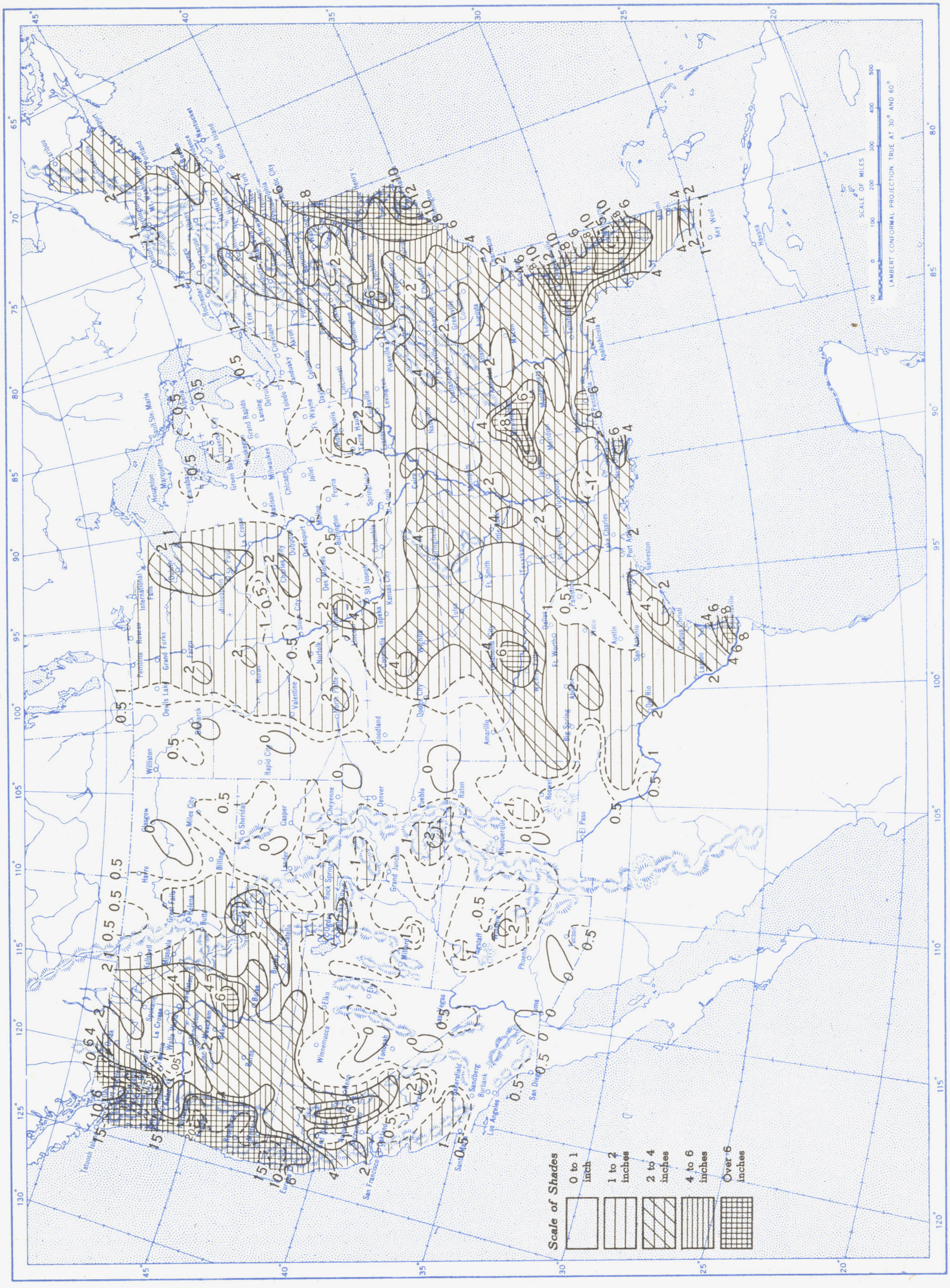


B. Departure of Average Temperature from Normal (°F.), October 1956.



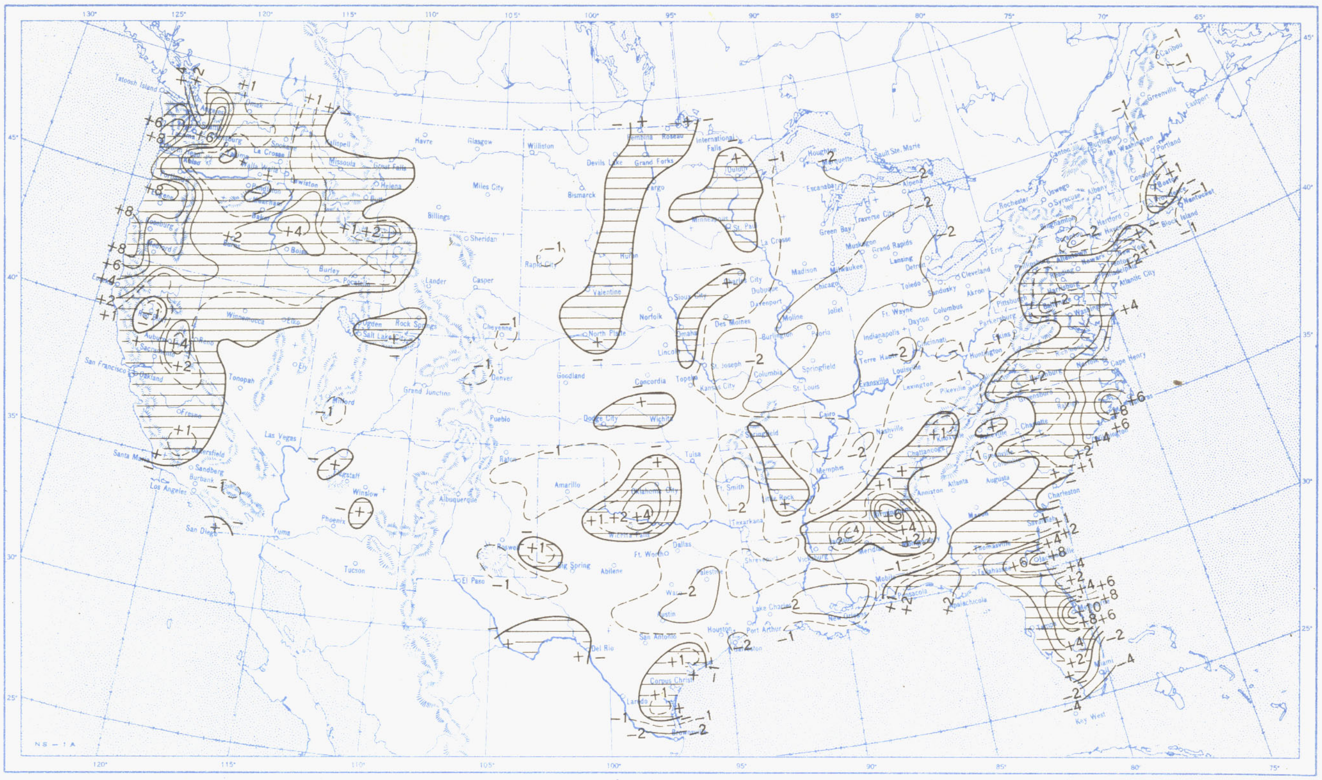
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), October 1956.

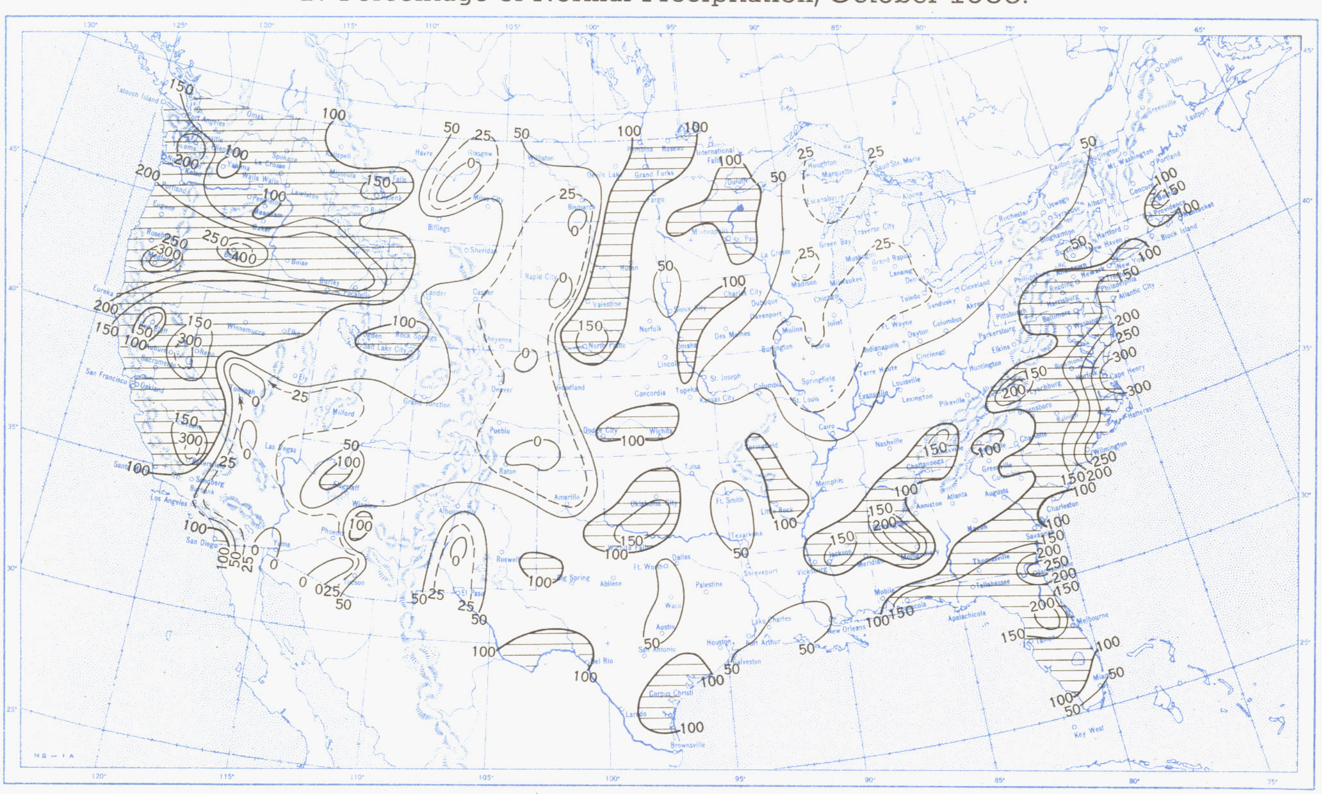


Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), October 1956.

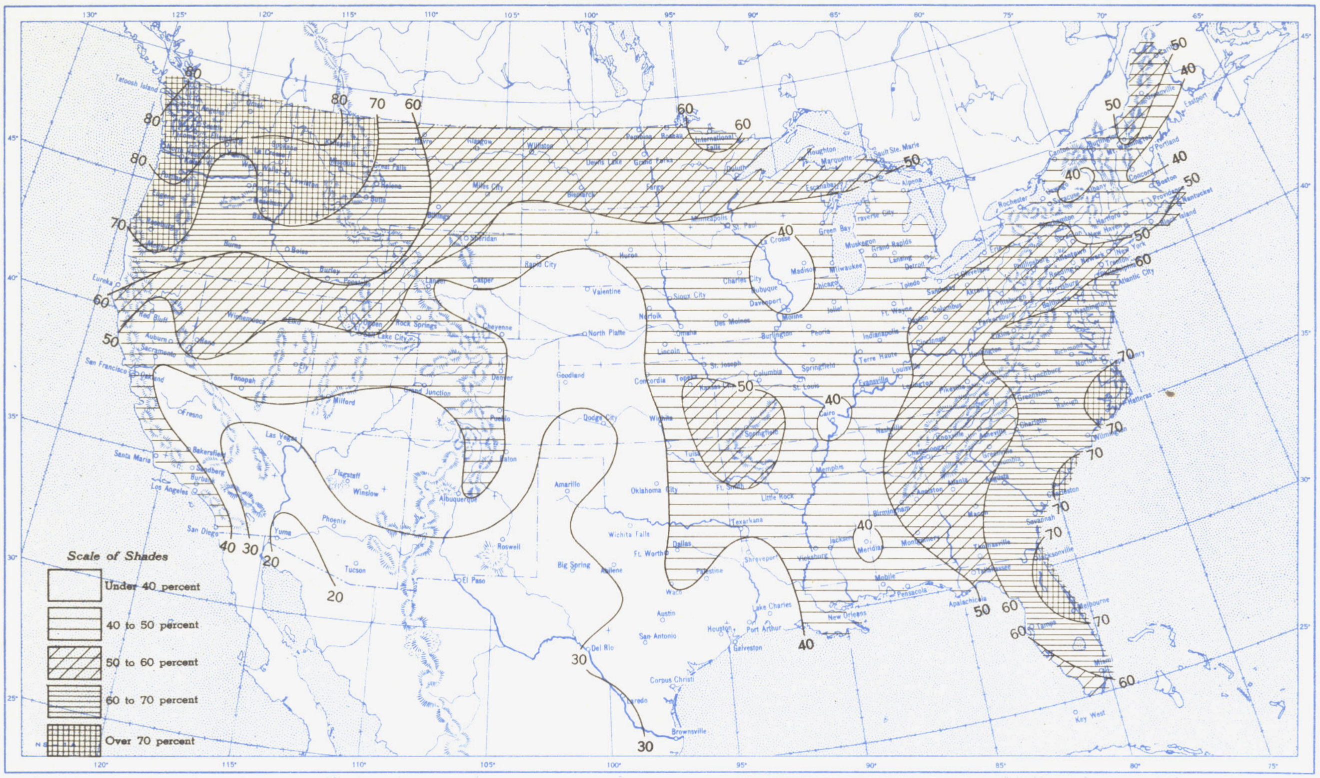


B. Percentage of Normal Precipitation, October 1956.

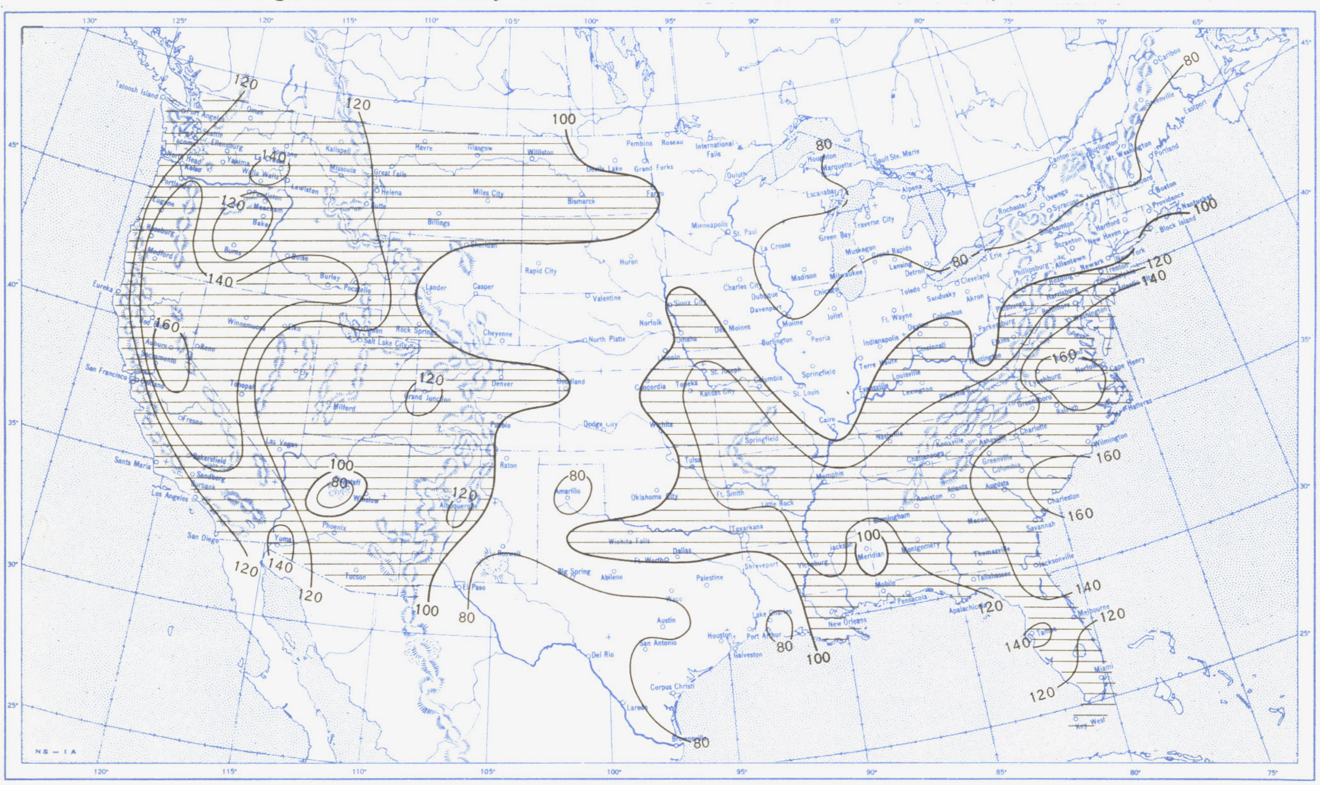


Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, October 1956.

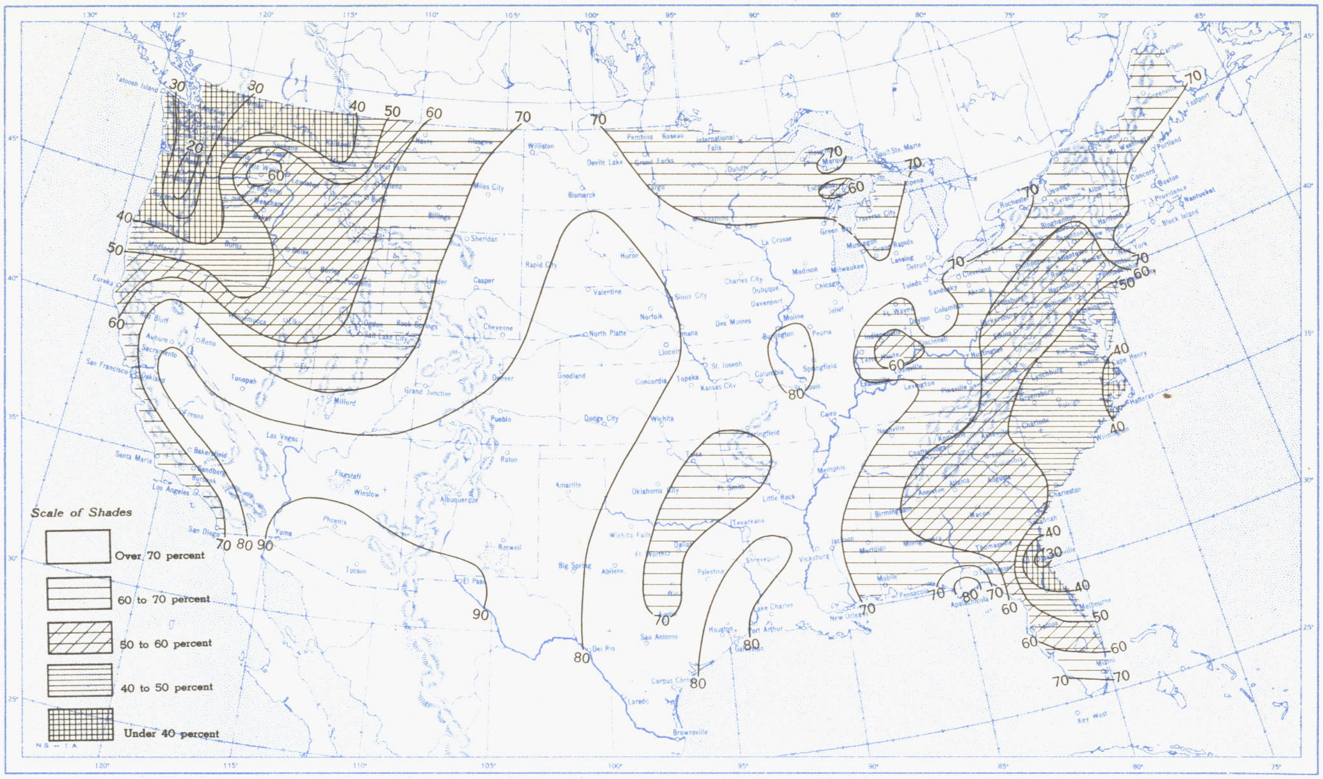


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, October 1956.

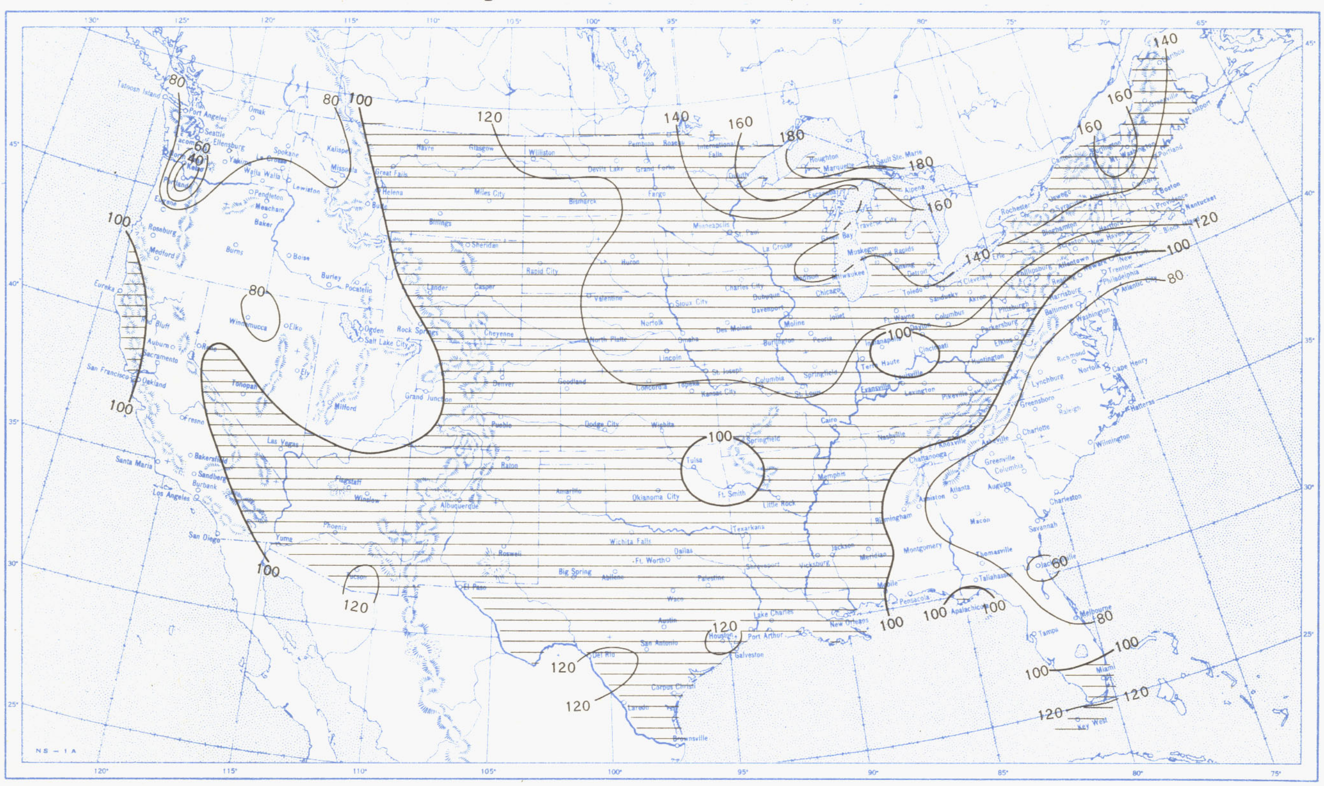


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, October 1956.



B. Percentage of Normal Sunshine, October 1956.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, October 1956. Inset: Percentage of Mean Daily Solar Radiation, October 1956. (Mean based on period 1951-55.)

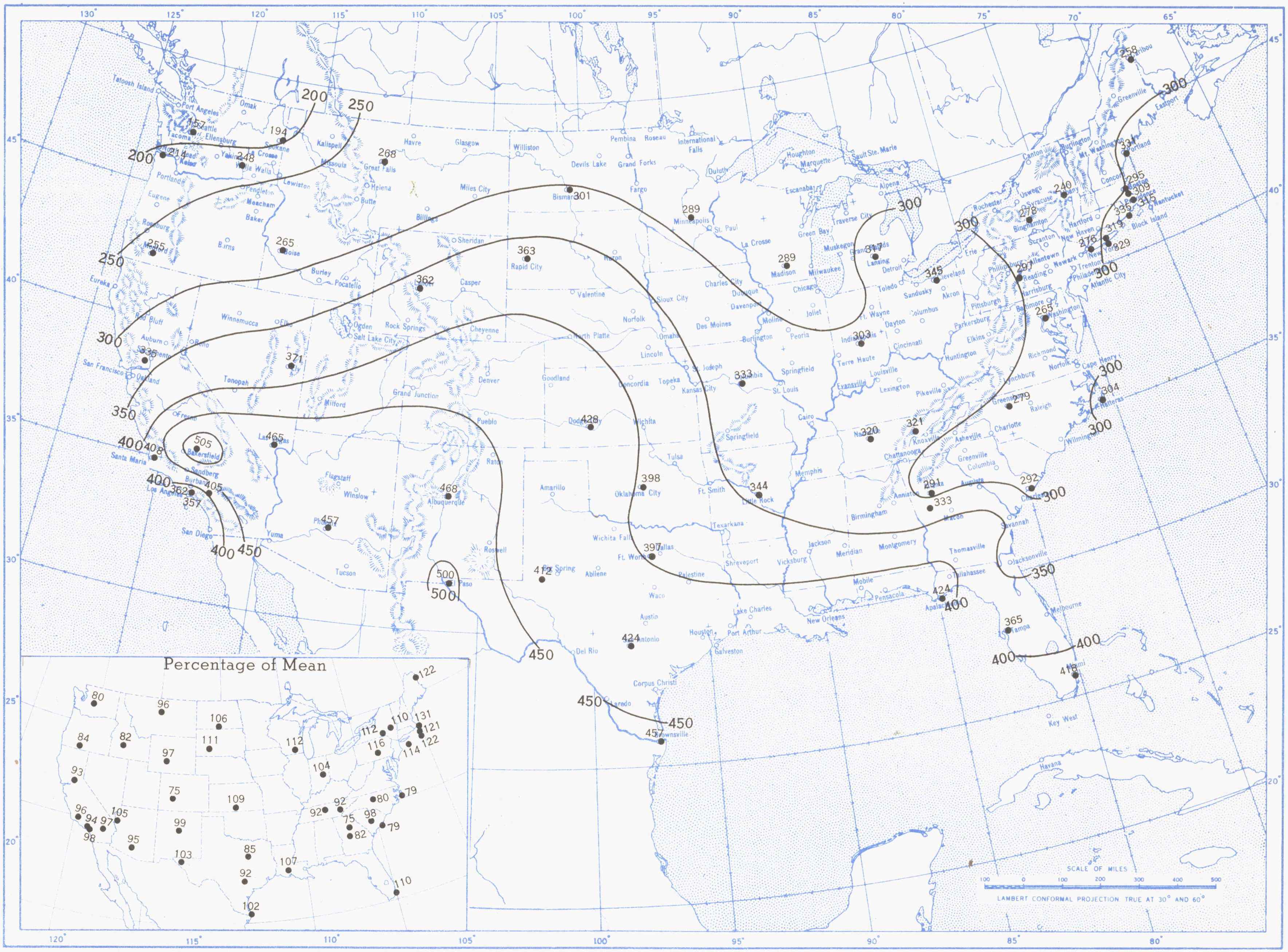
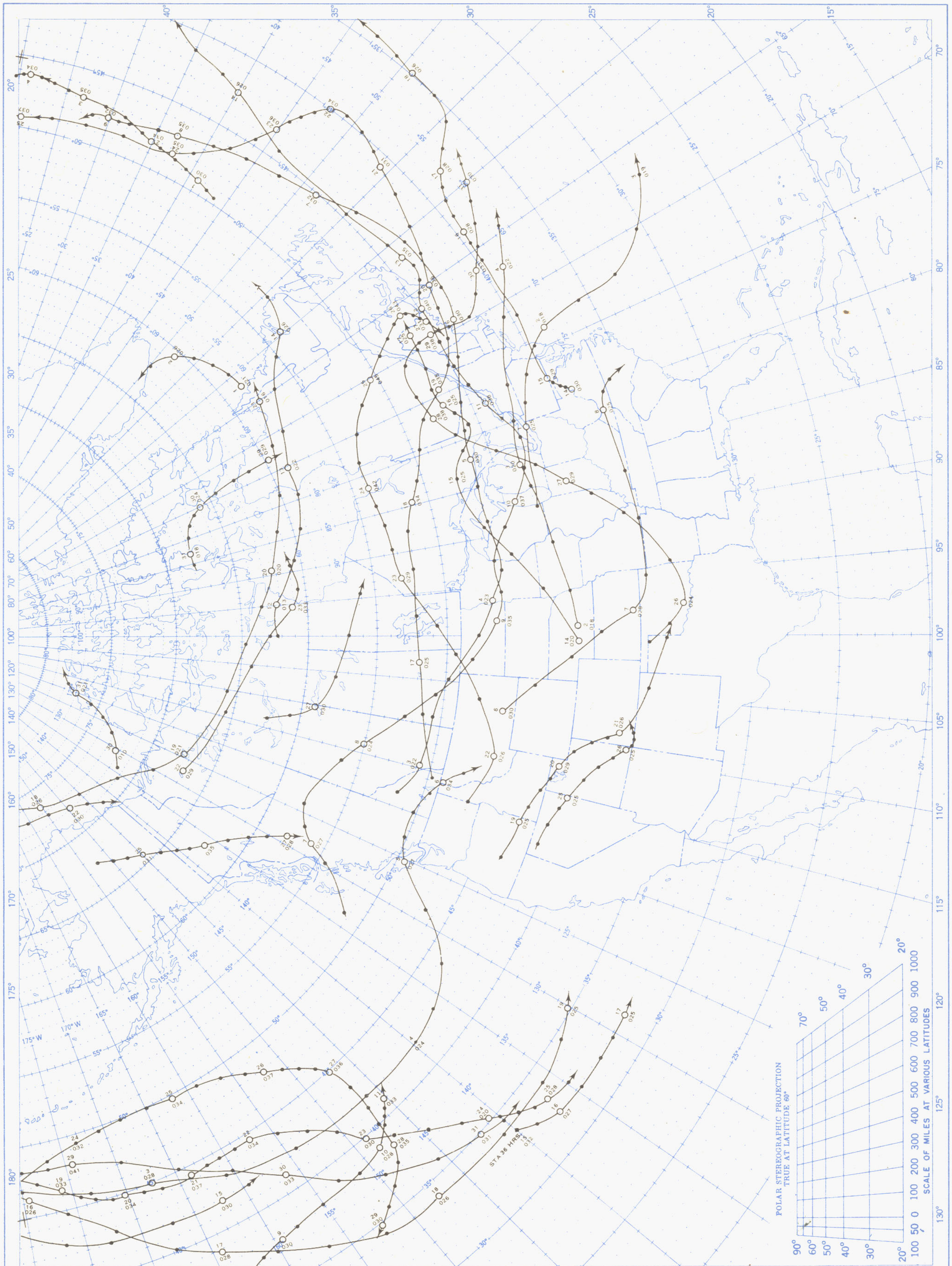


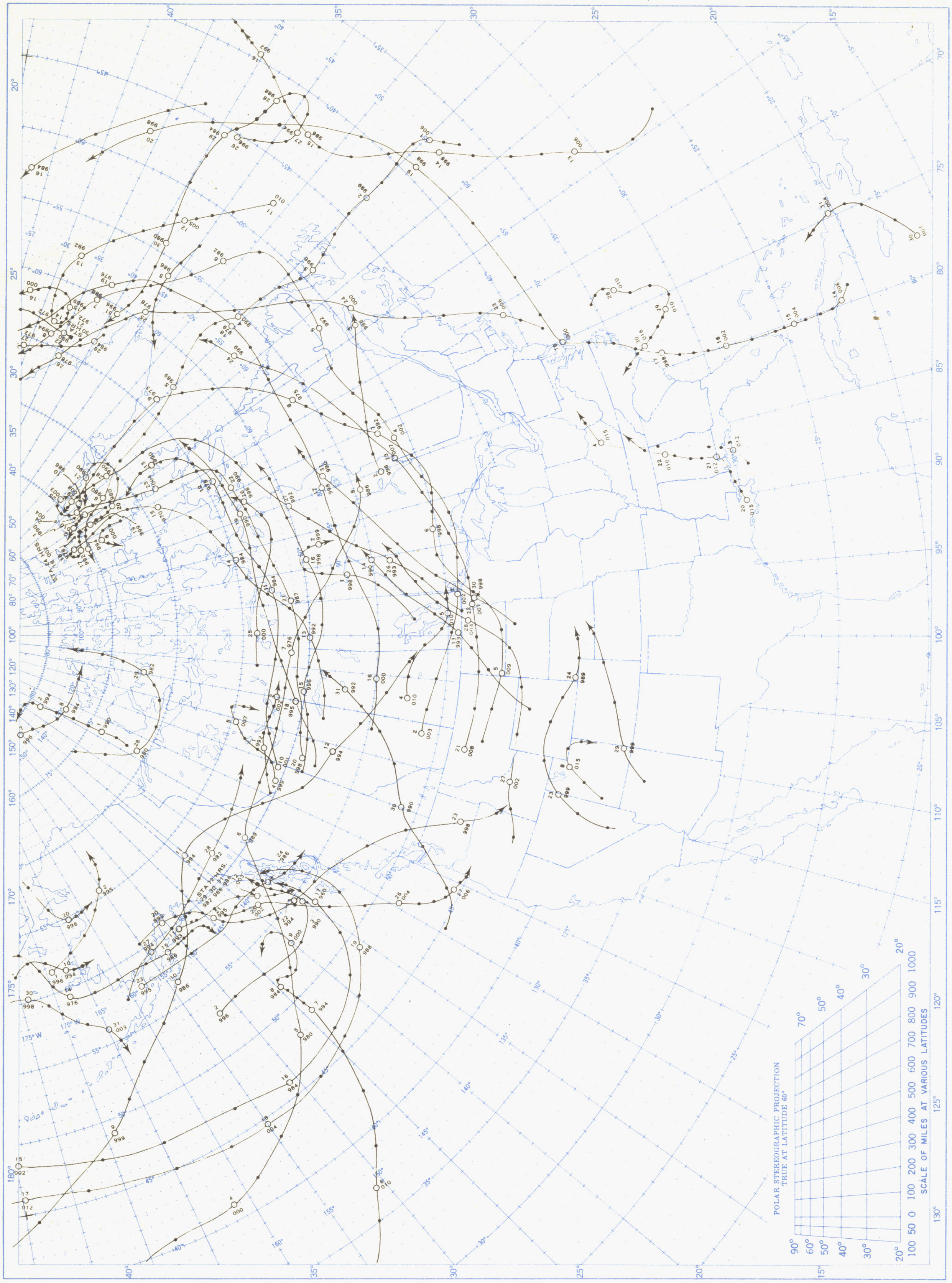
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, October 1956.



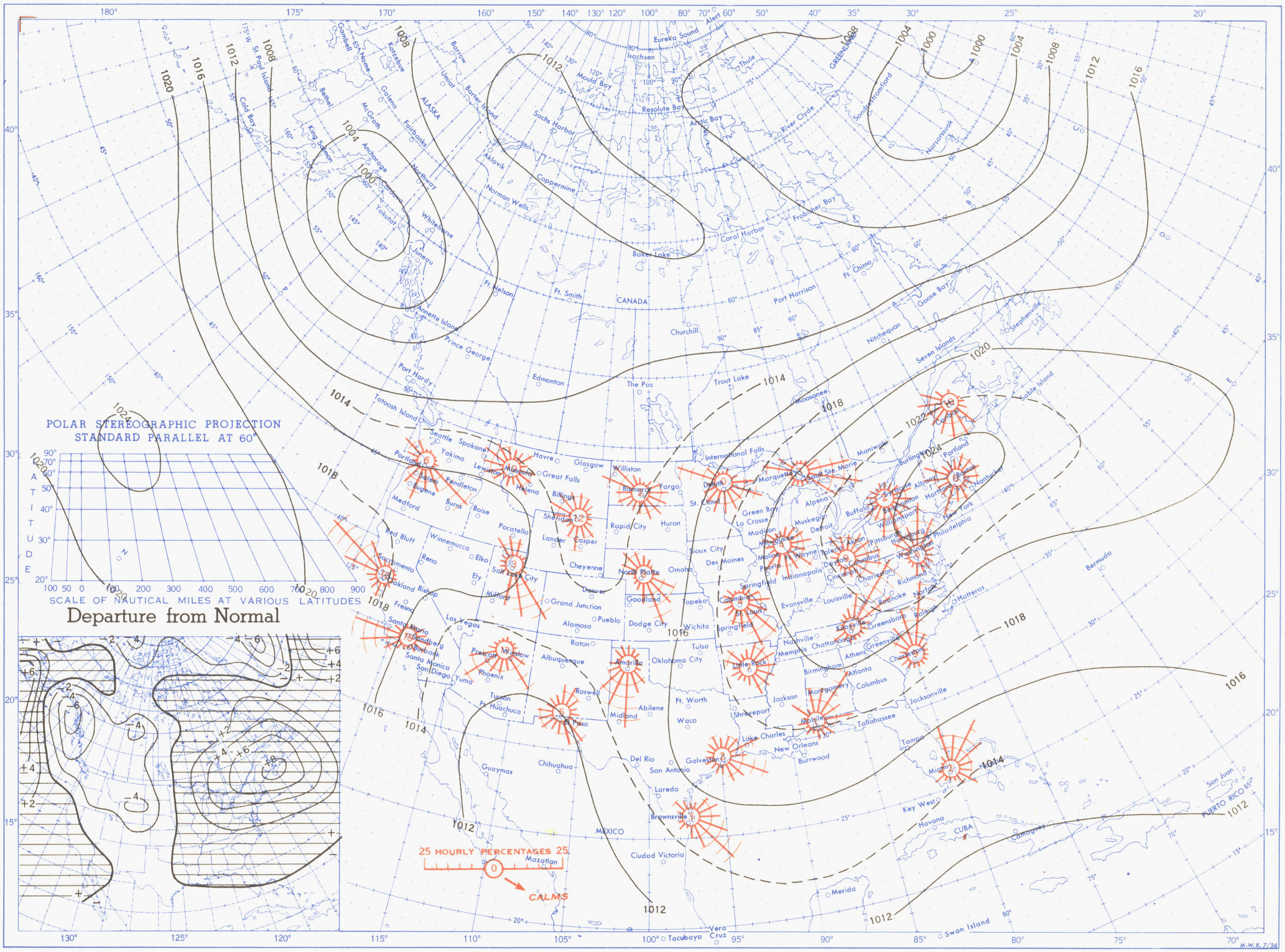
Circle indicates position of center at 7:30 a.m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, October 1956.



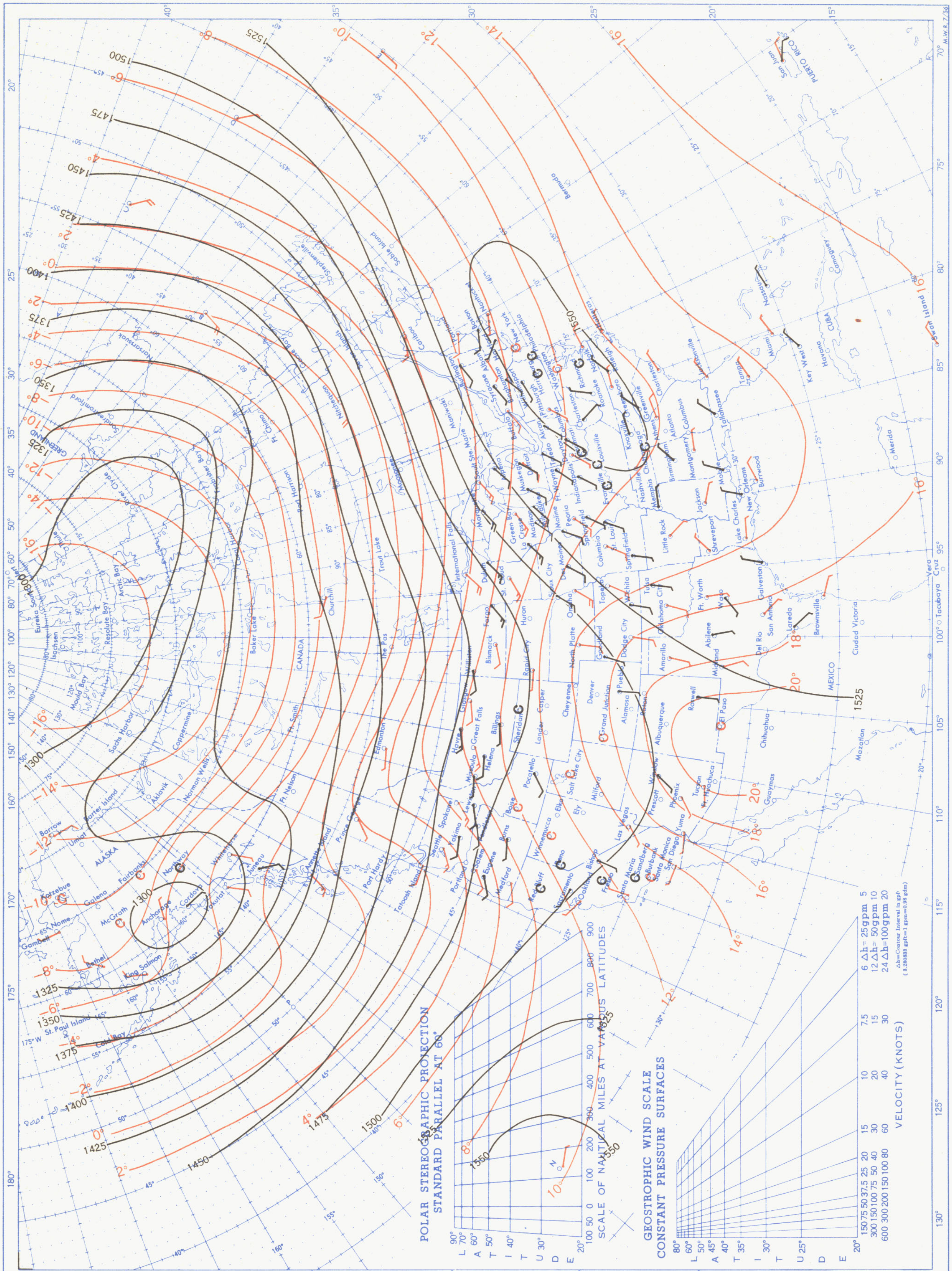
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, October 1956. Inset: Departure of Average Pressure (mb.) from Normal, October 1956.



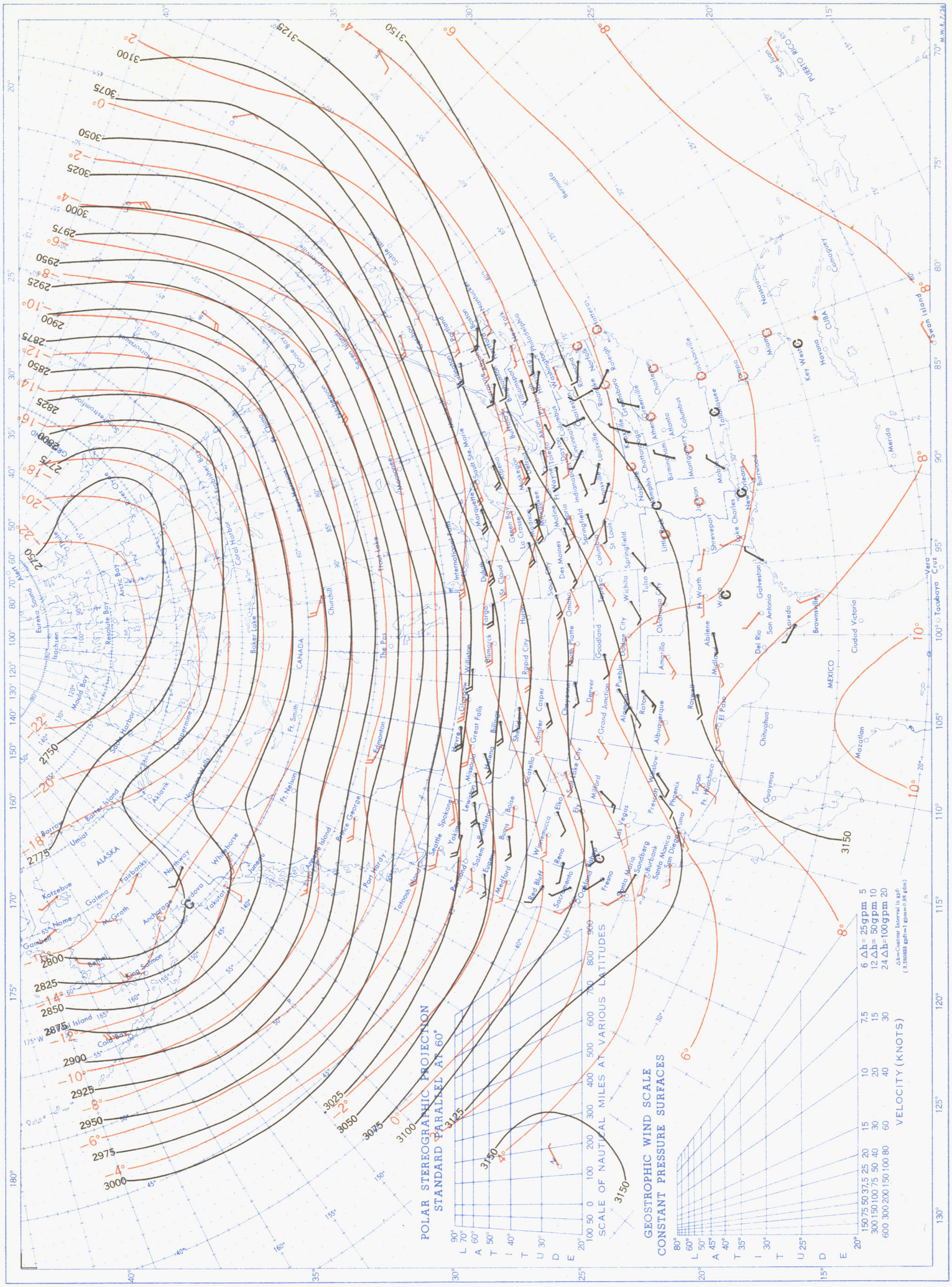
Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. 850-mb. Surface, 0300 GMT, October 1956. Average Height and Temperature, and Resultant Winds.



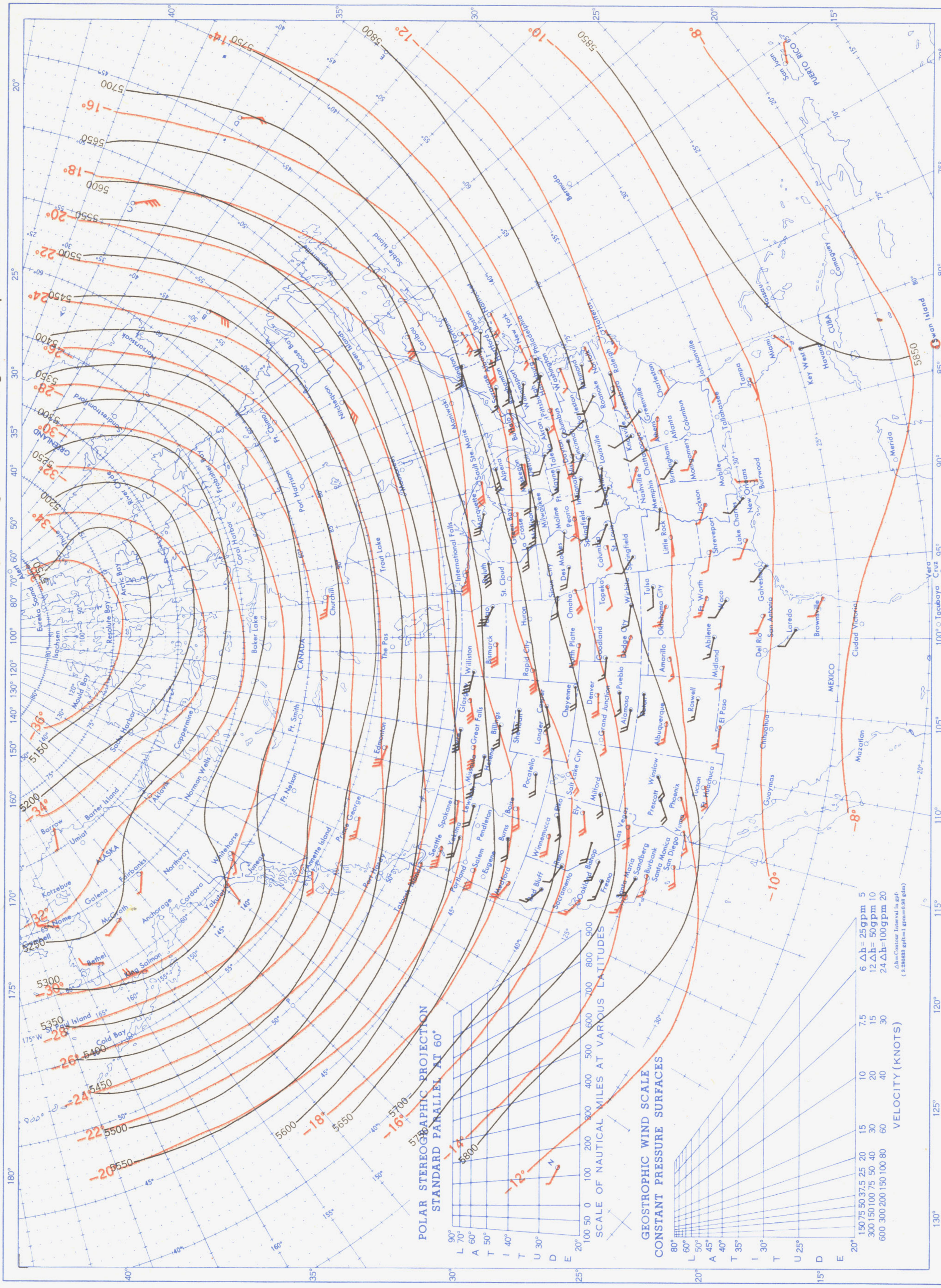
Height in geopotential meters (1 g.p.m. = 0.98 dynamic meters). Temperature in °C. Wind speed in knots; flag represents 50 knots, full feather 10 knots, and half feather 5 knots. Winds shown in red are based on rawins taken at the indicated pressure surface and time. Those in black are based on pibals taken at 2100 GMT and are for the nearest standard height level.

Chart XIII. 700-mb. Surface, 0300 GMT, October 1956. Average Height and Temperature, and Resultant Winds.



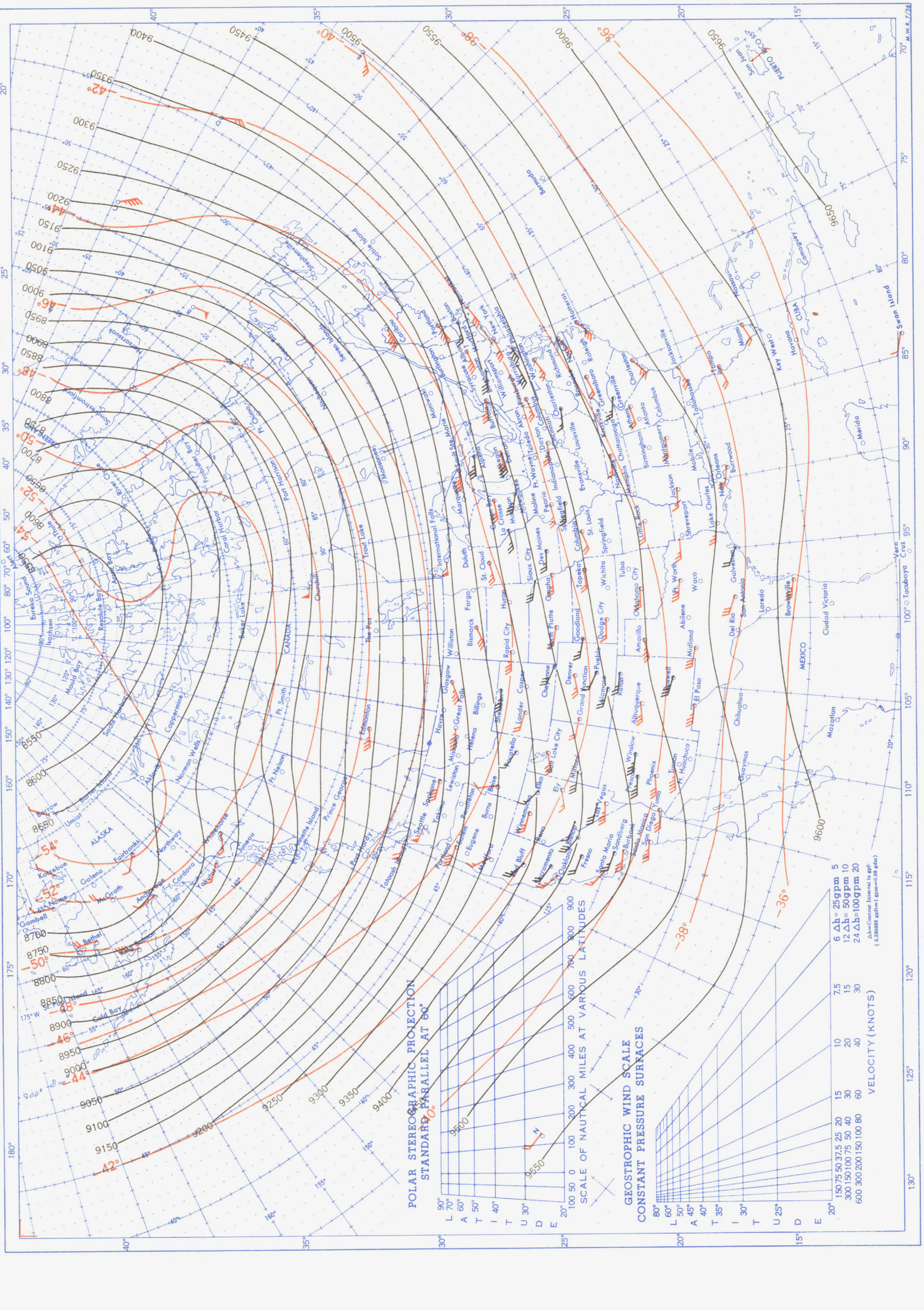
See Chart XII for explanation of map.

Chart XIV. 500-mb. Surface, 0300 GMT, October 1956. Average Height and Temperature, and Resultant Winds.



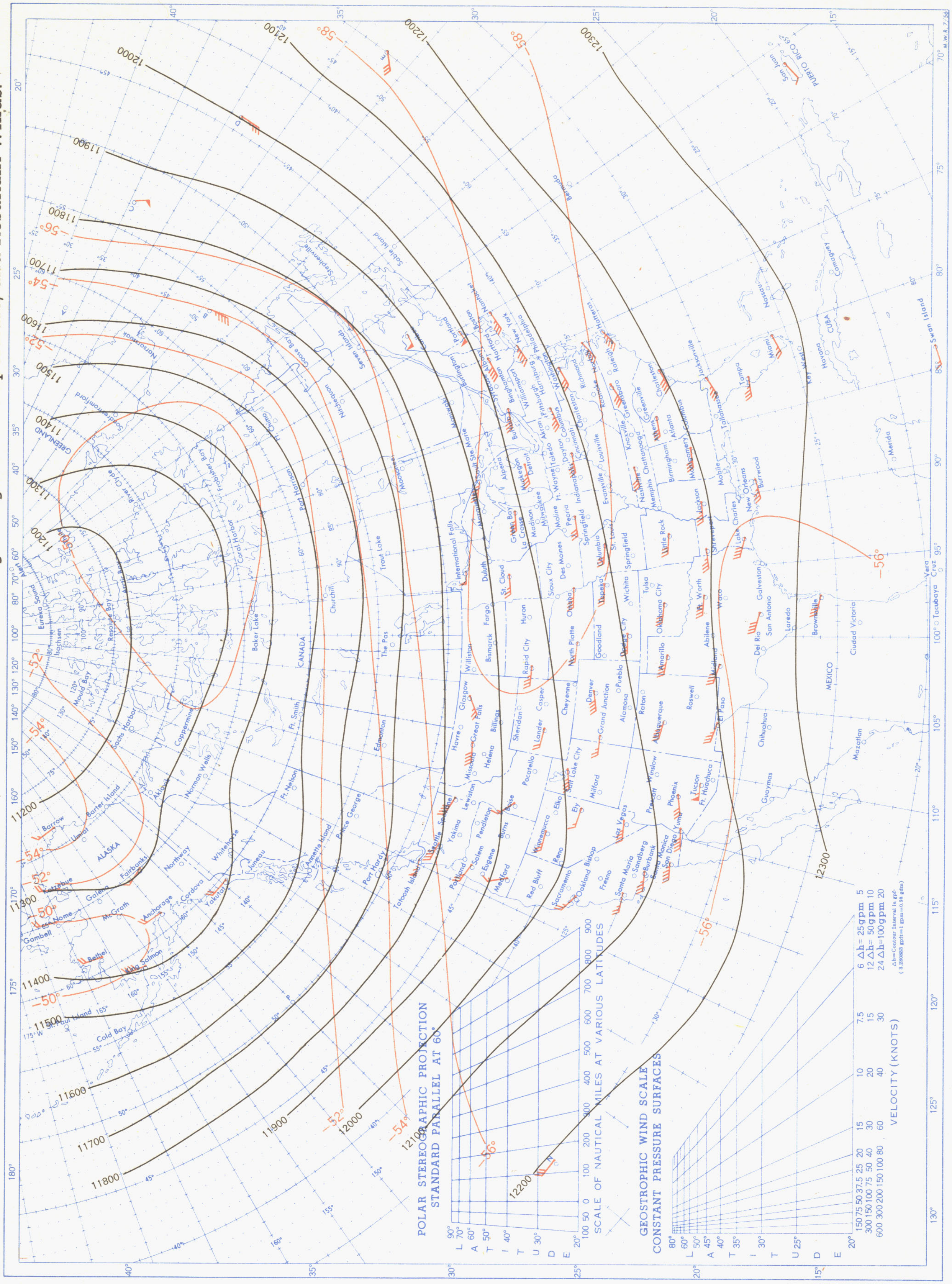
See Chart XII for explanation of map.

Chart XV. 300-mb. Surface, 0300 GMT, October 1956. Average Height and Temperature, and Resultant Winds.



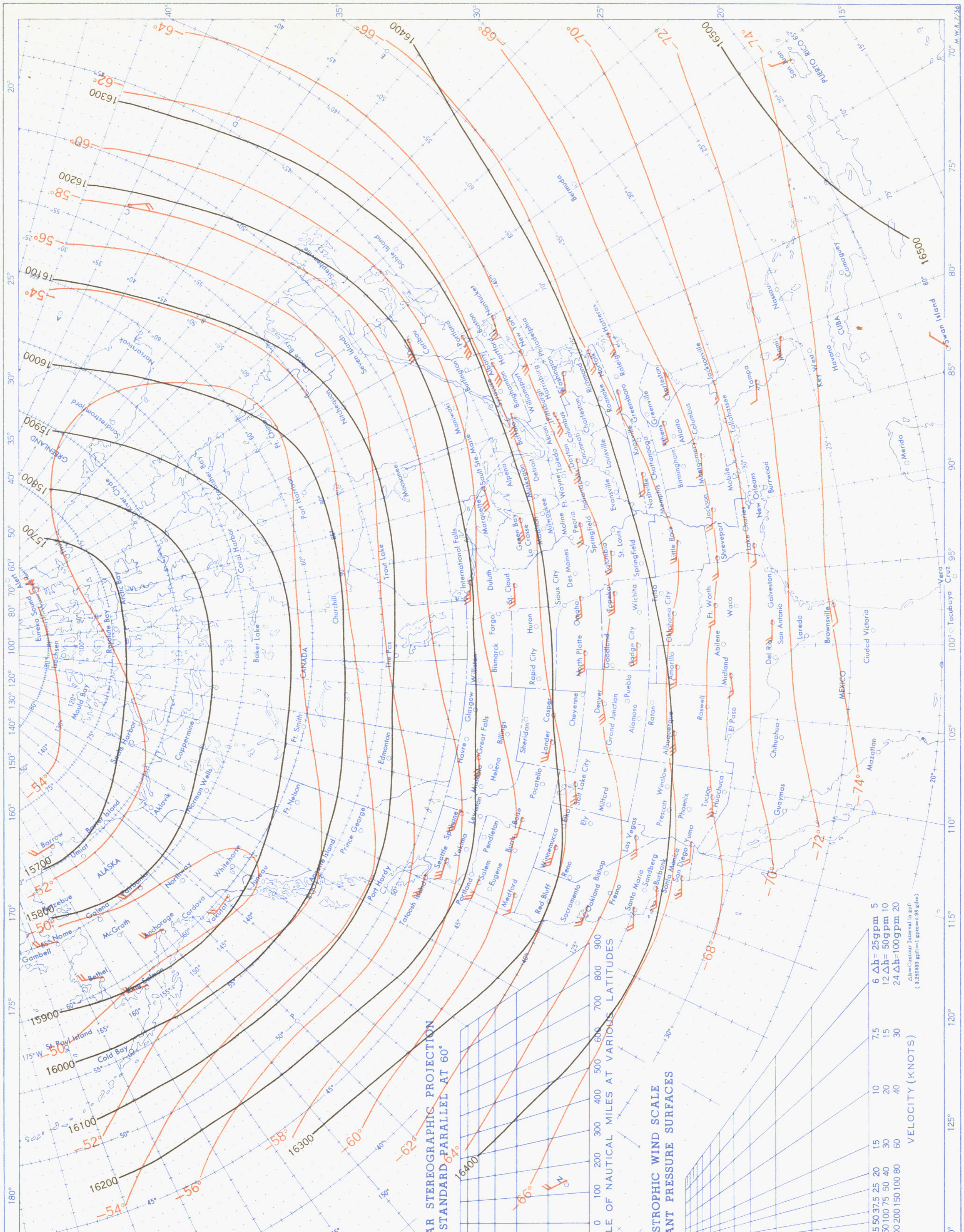
See Chart XII for explanation of map.

Chart XVI. 200-mb. Surface, 0300 GMT, October 1956. Average Height and Temperature, and Resultant Winds.



See Chart XII for explanation of map. All winds are from rawin reports.

Chart XVII. 100-mb. Surface, 0300 GMT, October 1956. Average Height and Temperature, and Resultant Winds.



See Chart XII for explanation of map. All winds are from rawin reports.